ASTRONOMY

FOR BOY SCOUTS AND OTHERS

ASTRONOMY

FOR

BOY SCOUTS AND OTHERS

BY

THOMAS W. CORBIN

AUTHOR OF
"THE HOW DOES IT WORK OF ELECTRICITY," "MODERN ENGINES,"
"ENGINEERING OF TO-DAY," ETC.

WITH EIGHT PLATES AND NUMEROUS DIA RAMS

London

C. Arthur Pearson, Ltd.

Henrietta Street

1910

PREFACE

ASTRONOMY is the oldest science; the first in which man took an interest. That was because of the open-air life which he had to lead in the old days. When men had to keep guard over their flocks and herds by night as well as by day, they naturally occupied themselves by watching the heavens. Moreover, since there were no books then, they had more inclination than we have to look about and see things for themselves.

Now the Scout movement is, to a certain extent, producing the old conditions once more. It encourages boys to live an outdoor life, and it teaches them, above all things, to keep their eyes very wide open indeed. It is not surprising, therefore, that the Boy Scout is becoming something of an astronomer, and the main object of this book is to help him.

With this in view I have given prominence to the ways in which he can find out astronomical facts for himself, but I have supplemented these with simple descriptions of how men have discovered the most striking of those other facts, for which we have to accept the word of the professional astronomer.

I have omitted any detailed reference to certain matters connected with the earth, such as the way in

which the Inclination of the Axis produces the seasons, and the cause of the Tides, since they are well taught to every boy at school.

I desire to express my sincere thanks to Mr. Stanley Maxwell, M.A., LL.B., F.R.A.S., who kindly read through my manuscript, and who made several valuable suggestions which I have embodied in the book.

T. W. CORBIN.

CLAPHAM,
October, 1910.

CONTENTS

LIST OF PLATES

LIST OF DIAGRAMS

ASTRONOMY

CHAPTER I

HOW THE SKY TURNS ROUND

IT is a great mistake to suppose that the study of astronomy is too "deep" for the ordinary person, or that it can only be pursued by the aid of expensive instruments. Of course, if you are interested in the subject it is nice to be a Senior Wrangler, or even a mathematician of less eminence, but it is by no means essential, nor is it absolutely necessary to possess even a small telescope. It will surprise some to know that the great fundamental truths about the solar system—the shape of the planets' orbits, their relative distances from the sun, and the speed at which they are travelling—were all discovered from observations made with the naked eye before the telescope was invented.

Indeed, any reader who has a pair of field-glasses or a photograph camera, or who cares to construct one of the simple telescopes which I shall describe later on, will be in some respects better equipped than was Tycho Brahé, the great Danish astronomer, who made the observations just referred to.

Astronomy

The Starting Point.

All systematic study of the heavens must start with the Pole Star.

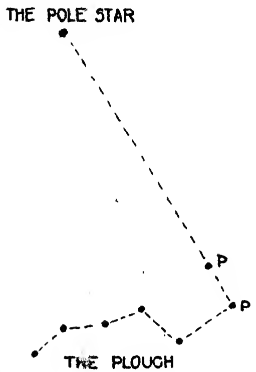
This star, which is also called by its Latin name Polaris and by its official title α (Alpha) Ursae Minoris, is to be seen any fine night by anyone in the Northern Hemisphere. It is not very bright, but belongs to the second degree of brightness, or second magnitude as it is termed; the best way to find it is by two other stars generally spoken of as the Pointers for that very reason, namely that they point to the Pole Star. These two belong to the Plough, which is the best-known group of stars in the sky.

The First Observation.

Most people know the Plough, but if you do not happen to do so it is easily found; for the seven stars which are its principal features form the outline of a saucepan with a bent handle; no one can look at the clear sky for many minutes without noticing it. Our friends in America call it the Dipper or ladle, and some speak of it as the Great Bear, but that is not quite correct, for the Plough is really only a portion of the constellation of that name.

The position of these seven stars is shown in the diagram Fig. 1, and the two marked "P" are the Pointers. If you imagine a line drawn through them like the dotted line in the diagram, it will lead you to the Pole Star. If, now, you go out one clear evening, find the Plough and then the Pole Star, you will have made for

yourself a real astronomical observation, as real, in its way, as any observation ever made at Greenwich Observatory. Have a good look at the Pole Star when you have found it, so that you will be sure to know it again, for you will often need its aid if you are going to study the stars.



First find the seven stars which orm "the Plough." Then imagine a line drawn through the two stars marked P (the Pointers as they are called), and that line will lead the eye to the Pole Star.

The Pole Star is about six times as far from the nearest Pointer as they are from one another.

FIG. 1. HOW TO FIND THE POLE STAR

The Pole Star always due North.

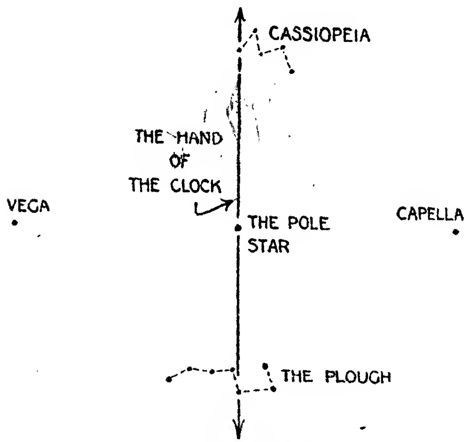
It may be a good friend to you for other purposes as well, for it is always lying due north; stand facing it and you may be quite sure you are looking towards the north; so that if ever you should lose your way on a clear night it may help you to get home.

Having found these stars, look at the other side of the Pole Star, the side, that is, away from the Plough; there you will find five stars, forming what looks like a badly made letter W, a part of the constellation Cassiopeia. This is a little nearer to the Pole Star than

the Plough is, and all three are shown in the diagram, Fig. 2.

Vega and Capella.

So far none of the stars that we have found are brighter than the second magnitude. If, however, we start from the Plough and with our eyes follow



The hand is hereshowing noon (Sidereal time).

The hand horizontal, with the Plough to the right = 6 o'clock.

Vertical, with Plough at the top = 12 o'clock.

Horizontal, with Plough to the left = 18 o'clock.

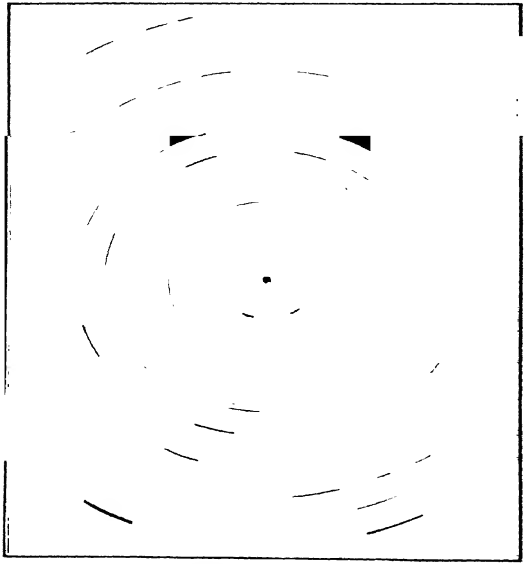
Other times in proportion.

(See page 45.)

FIG. 2. THE CELESTIAL CLOCK

round an imaginary circle of which the Pole Star is the centre, in the same direction that the hands of a clock move, we shall come to Vega, a star of the first order of brightness, or of the first magnitude.

It is of a bluish tint and can be easily identified, while just opposite to it, on the other side of Polaris, there is another first-magnitude star, Capella by name.



AROUND THE POLE

This diagram was made from a photograph of the region around the Pole Star. The stars can be clearly seen in the photograph, but are too faint to be reproduced here.

NEARER THE HORIZON

This sketch, also made from a photograph, shows that the apparent motion round the Pole Star is shared by all the stars and by the planets too, for the prominent line in the left-hand bottom corner is Jupiter.

To face page 17

These four, then, the Plough, Cassiopeia, Vega, and Capella, form a kind of four-armed guide-post, pointing to the four quarters of the sky. They are something like north, south, east, and west are upon the earth, and make it quite easy to describe the positions of the other stars.

How the Sky goes round.

I once wrote something like the above in an article, and one reader fell into the error of thinking that the Plough would always be in the north, Cassiopeia in the south, Vega in the east, and Capella in the west, so that when he saw, one night, that Vega was in the south he wrote to ask me what was the matter. I had then to explain to him that these four points in the sky do not correspond to the earthly "points of the compass," but only serve a similar purpose, for the sky is continually *on the move.* If Capella, for example, is in the north to-night at ten o'clock, he will be in the east by four o'clock to-morrow morning, for the whole of the sky turns round as if it were pivoted upon a point once in about twenty-four hours.

Another Interesting Observation.

The next clear night go out into the open, or to a window, and look at the stars; fix upon a bright one near to the horizon, if possible to the south, and notice how far it is from a tree or other fixed object. Soon you will perceive that this star is moving. If you are looking to the south, it will be moving from east to

west; if to the north, beyond the Pole Star, from west to east. If you look to the west, you will see stars setting, going down below the horizon, just as the sun does every evening, while fresh ones will be coming up from below the horizon in the east.

An Observation by Photography.

Nowadays astronomers very often use photography. Instead of watching a thing through a telescope they take a photograph of it. You can do the same. Plate I is a photograph which I took one night with just an ordinary quarter-plate camera, with the ordinary lens—nothing special about it at all—which shows perfectly the turning of the sky. I set the camera at what I knew to be the correct focus for distant objects, placed it upon the seat of a chair out in the open with the lens pointing upwards, and left it for half an hour. During that time the stars moved, so that instead of appearing as stars they imprinted themselves upon the plate as lines, as you will see.

You will notice, too, that the lines are not straight, but are curved, and that they form parts of circles, all of which have the same centre.

That centre is the pivot, as it were, on which the sky turns, and, as the photograph shows, it is nearly marked by a star, the one star in the whole picture which is almost represented by a point.

That star is our old friend Polaris; it is the one star in the whole sky which never, so far as we can tell with the eye alone, changes its position. The fact that

the photograph reveals it as having moved slightly shows us that in the ordinary small camera we have a useful astronomical instrument.

Why call them Fixed Stars?

This will probably raise the thought in someone's mind, "If they are all moving, why are they called 'fixed' stars? There appears to be only one 'fixed' star, and that is Polaris." The answer is that all the millions of stars in the sky, except (as far as the naked eye can tell) five, seem to move together. They don't appear to get any nearer to each other, nor any further apart; but the five, several of which are very conspicuous because they are so bright, move differently.

They seem to be moving about *among* the others like a fussy, restless man wandering among a crowd of waiting people; therefore these five are called "Planets," which means wanderers, while for distinction all the rest are called *fixed* stars.

Apparent Motion.

But, in truth, this motion of the stars which we have been watching, and which we have seen recorded upon our photograph, is not really motion at all: it is what is called "apparent" motion; it is an optical illusion. Many of the "fixed" stars, as we shall see later, have motion of their own, quite independent of each other, which astronomers are able to measure, yet even the fastest of them is moving so slowly that it takes the most careful measurements and a very long period to detect it. For our present purpose, then, we may regard

them as being quite still, except for this apparent motion, which affects them all equally.

The movement of a star peculiar to itself is called its "proper" motion; that which it has in common with all others, its "daily" motion.

What, then, is this apparent motion? It is just like the motion of the landscape when we are on a journey by train. We have all looked out of a railway carriage window and seen houses and trees, fields and bridges, churches and villages, *apparently* rushing past like a long procession, yet we know that such things as I have named never do rush about; they never even appear to do it when we are standing still; in fact, when the train slows down they slow down too, and when the train stops, they stop. That motion, then, is "apparent" motion, the trees, etc., simply appearing to move because we are moving.

In just the same way the motion of the stars which we see, or at all events think we see, is simply due to the fact that we are moving; we are living upon a large spinning top, which is whirling us round and round, yet we are moving so smoothly that we forget the fact, and so when we look at the heavens they seem to be moving round and round instead. The reason Polaris does not seem to move is because it is very nearly in line with the earth's axis.

Another Observation.

Now let us see if we can tell how fast they are moving. Take a look at the stars one night and

notice carefully the direction of some particular star. If possible get it in line with two fixed objects; then the next night at the same hour look in the same direction again and see if the star is in the same place. You will find that it is, approximately, and then you will know that the sky appears to turn round once in about twenty-four hours; and from that fact you will deduce the further one that *the earth* turns round once in about twenty-four hours. This you doubtless know already, but you probably only know it because you have been told so; from this observation you will get the information first hand.

Now let us just see how far we have got. We have found Polaris and also four other stars or groups of stars which point out the four directions in the heavens; we have seen, too, that the whole sky seems to be moving round us as if on a pivot; that Polaris marks the position of the pivot; and that the stars take about twenty-four hours to complete this journey round Polaris.

Last of all, we have seen that the stars are not really moving at all, but that it is our earth which is moving and which makes them appear to move.

CHAPTER II

THE CELESTIAL MENAGERIE

WE cannot well study the sun and the planets without first knowing some more of the stars. For, you must remember, we are standing, as it were, upon a moving platform, our earth being constantly in motion; the sun and planets too are moving, or appear to be; so that it is a great advantage if we can find some thing or things which are still, since they will furnish us with a convenient means of watching and measuring the movements of those that are moving.

The Stars form the Background.

That is how the stars will help us. They have no real movement at all that need trouble us at present, but form a perfectly steady background, in front of which the other bodies perform their evolutions.

As we shall see, for example, the true period of the rotation of the earth is not to be found by reference to the sun, for it moves, but by reference to the stars. In the same way if we want to state where Jupiter or one of the other planets is at any particular moment, it is very convenient to be able to name the constellation in front of which he happens to be, and, wonderful to

relate, by measuring the apparent distance of a small planet from a fixed star at different times, we are able to tell how far off the sun and all the planets are.

In this chapter, therefore, we will consider specially those constellations which lie in what is called the "Zodiac." This is a strip of sky forming a complete band all round the heavens, and in some part or other of it the sun and all the planets are always situated. The name "*Zo*diac" comes from the same Greek word that gives us "*Zo*ology," because so many of these constellations are named after animals. This explains the title of the chapter.

The Names of the Constellations.

This band passes through twelve constellations, and their names and order are shown in the following well-known rhyme:—

The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
  The Virgin and the Scales,
The Scorpion, Archer, and He-goat,
The man that holds the Water-pot
  And Fish with glittering tails.

Put in more scientific language, the list is like this:—

1.	Aries (the Ram) . . .	March 21.
2.	Taurus (the Bull) . . .	April 19.
3.	Gemini (the Twins) . . .	May 20.
4.	Cancer (the Crab) . . .	June 21.
5.	Leo (the Lion)	July 22.
6.	Virgo (the Virgin) . . .	August 22.
1.	Libra (the Balances) . .	September 23.

2.	Scorpio (the Scorpion) . .	October 23.
3.	Sagittarius (the Archer) . .	November 22.
4.	Capricornus (the Goat) . .	December 21.
5.	Aquarius (the Water-carrier) .	January 20.
6.	Pisces (the Fishes) . . .	February 19.

The Sun's Yearly Journey.

The sun passes through all these in one year in the above order, moving always from west to east, so that at the end of twelve months he is back in the same constellation that he started from. If only our earth did not rotate this would be easy to understand, but as it is we are apt to get confused over the fact that all heavenly bodies (the sun included) move from east to west, and yet, we are told, the sun moves from west to east as well. It seems as if the sun is moving both ways at once, "which is absurd," as our old friend Euclid says.

We can make it clearer by this analogy. Suppose we are travelling by train and in the distance is a road parallel with the line; along this road a motor-car is moving in the same direction as our train but at a slower speed.

Now assuming that we are looking out of the right-hand window of the railway carriage we shall see all things, motor-car included, apparently flying past us from left to right; but if we concentrate our gaze upon the motor-car and its immediate surroundings we shall see that it is moving from right to left. We become conscious of that motion from the fact that it is passing

in front of houses, trees, and other fixed objects; we forget for the moment the left-to-right motion of everything, and only notice that *in relation to the fixed objects* the motor-car is passing from right to left.

In the same way we must forget the daily motion of the whole heavens and concentrate our attention upon the sun and the fixed objects (namely, the stars), in front of which it is travelling. Then we can see quite clearly that it is moving from west to east.

But you will probably say, "When the sun is seen there are no stars, so how can we tell that he is moving among them?"

The stars are there, but they are overpowered by his brightness, yet we can watch his progress just the same. You can do it for yourself.

Observations to show the Sun's Movements.

Look at the sun one morning and note the direction in which he lies; then look at the sky exactly twelve hours later and see which of the zodiacal constellations lies in the same direction that the sun was in in the morning. Now during that twelve hours the sun and the stars among which he is situated will have moved just half-way round the earth, so that they will in the evening be round the other side of our globe, exactly *opposite* where they were seen in the morning.

If, then, we find that the constellation Taurus, for example, is in the same direction that the sun was in twelve hours earlier, we know that the sun is at the same

time in the constellation exactly opposite to Taurus, namely, Virgo.

If circumstances allow us to be up at midnight, our observations become simpler still, for the sun is always to the south at noon, so that whichever of the zodiacal constellations is south at midnight is opposite to the one where the sun is. Or another way to tell the same thing is to observe the *full* moon. When the moon is full it always appears to us in the exactly opposite direction to that of the sun. Therefore the constellation that it appears to be in will be the one opposite to that where the sun is.

Make any of these observations at intervals, and you will perceive that the sun is moving among the stars.

The positions of these constellations can be found from the table on pages 143 and 144. The course of the moon among the stars, too, gives us a good guide where to look for them, for the moon is always somewhere in the Zodiac.

The Signs of the Zodiac.

Now we come to what, if we are not careful, may be a pitfall. There are the constellations of the Zodiac and there are the signs of the Zodiac; they both have the same series of names, yet they do not mean the same thing.

The Ecliptic.

The line along which the sun travels is called the Ecliptic, and the Zodiac is that part of the sky which

lies within a certain distance (eight degrees) above and below it. This circular band is divided up lengthwise into twelve equal parts, each of which is therefore the twelfth part of a circle. These are the "signs of the Zodiac," and ages ago each one occupied the same position as the constellation of the same name. The starting point of the "signs" is the "first point of Aries" or the beginning of the sign Aries, and that coincides with the position of the sun at the Spring Equinox on the 21st March, when the sun crosses the Equator. Or we may think of it in this way. There are two great circles which astronomers imagine drawn round the sky: one is the Ecliptic or path of the sun, and the other the Celestial Equator, a line exactly over the earthly Equator; they are the same diameter, but have different centres, and one of the points where these two circles cut each other is the "first point of Aries."

How the Signs of the Zodiac have moved.

Now owing to a slow change which is taking place in the position of the earth's axis called the "Precession of the Equinoxes," this point is gradually moving, so that whereas it was once in Aries (hence its name) it has now moved into Pisces. Thus the sign Aries about coincides with the constellation Pisces, the sign Taurus with the constellation Aries, the sign Gemini with the constellation Taurus, and so on.

Against the names in the above list there are dates, each of which indicates the day when the sun enters the "sign" of that name, and when we see in a calendar

"sun enters Taurus," or some other name, it is the sign that is meant. When, however, a planet is said to be in Virgo or Cancer, or any of the others, it is usually the constellation and not the sign that is referred to.

We may picture the Zodiac to ourselves in this way. Imagine a race-track at which athletic sports are being held; it is surrounded on all sides with a belt of trees, and at some spot, on a level with the runners, we are standing watching; whichever way we look we see them standing out against a background of foliage; it is by reference to that background that we are best able to follow their movements and judge their speed; by some outstanding feature in it we can tell where the starting point was, and where the tape will be held when they reach the last lap. In the same way, precisely, the background of stars forms the best means of following the movements of the sun and planets. By its aid we can, as we shall see, watch the curious movements of the planets, see them go first one way and then another, sometimes standing still, at others moving comparatively rapidly.

Having now heard where to find this wonderful celestial race-track, we can proceed to watch some of the celestial athletes and examine their "performances," but before doing so I will describe a simple method of making charts of the stars by means of photography.

Making Star-Charts by Photography.

A photograph like plate No. 1 is excellent for showing the movement of the sky, but it is not easy to see

the arrangement of the stars when they are represented by streaks. On the other hand, a short exposure, which, theoretically, should record the same stars as points, does not, in fact, record any at all, except the brightest.

There is a method, however, by which we can convert these long-exposure photographs into beautiful little star-charts.

Take a print off your negative on P.O.P. Then with a fine needle make a small perforation at one end of each streak, taking care, of course, to prick the corresponding ends of all the streaks. It is not difficult to vary the size of the holes in accordance with the thickness of the streak. Having done this, expose the paper to the light so as to obliterate the streaks; then tone and fix. If mounted behind a "cut-out" mount with a piece of tissue-paper at the back this will produce a charming little star picture.

Held up to the light, the stars shine out just as they do in the sky, and a series of these giving the chief constellations is a work of which any amateur astronomer might be proud.

CHAPTER III

FATHER SUN AND HIS WAYS

WE must always remember that the sun is only a star.

It is just one of the fixed stars, like Polaris, Vega, and the rest of them. Moreover, as stars go, it is not very large. For example, if he were removed to the distance of the brightest star, Sirius, he would appear to us like a star of the third magnitude, less bright than those in the "W" of Cassiopeia.

The Nearest Star.

The reason why he seems to us to be so big is because he is, comparatively, quite near. He is only about 92,900,000 miles away, a mere nothing by comparison with the distance of Alpha Centauri,[1] the next nearest star, which is 275,000 times as far. The light from the sun reaches us in about eight minutes, but that from Alpha Centauri takes about *four and a half years.*

When the nearest star (other than the sun) is so far away as that, is it to be wondered at that they give such a feeble light, when compared with his; and

[1] Alpha Centauri is not visible in the Northern Hemisphere.

practically no heat, whereas he supplies all the heat that we need? Yet we must not forget that he is one of them.

The sun, however, stands to us in a special relationship, quite different from any other star; for besides being near to us he is head of the family to which our earth belongs.

Is the Sun a Fixed Star?

The first thought that occurs to one in this connection is: "If the sun is one of the stars, how is it that he is not fixed as they are?"

It is quite true that in the last chapter we spoke of the sun travelling through the twelve constellations of the Zodiac once in a year, but that is only another instance of apparent movement.

Just now I used the analogy of a motor-car passing in front of houses or other fixed objects to illustrate the movement of the sun among the stars, but that is not quite accurate. The motor-car really does move, while the sun is not moving any more than the other fixed stars.

We can now use a more accurate illustration.

An Interesting Experiment.

Go out into a field or common and select an isolated tree.

Stand some distance away and take a good look at it, noting where it appears to stand against the landscape behind it.

Then walk round it, every now and then stopping to have a good look at it, and every time you do that it will appear against a different part of the background, until, when you get back to your starting point, it too will be seen back in its old position. Of course you know you are walking round it, but if you were carried in a perfectly smooth-running vehicle, so that you did not know you were moving, it would seem as if you were still and the tree going round.

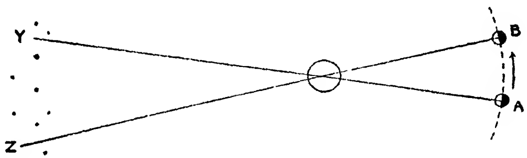


FIG. 3. WHY THE SUN APPEARS TO MOVE AMONG THE STARS

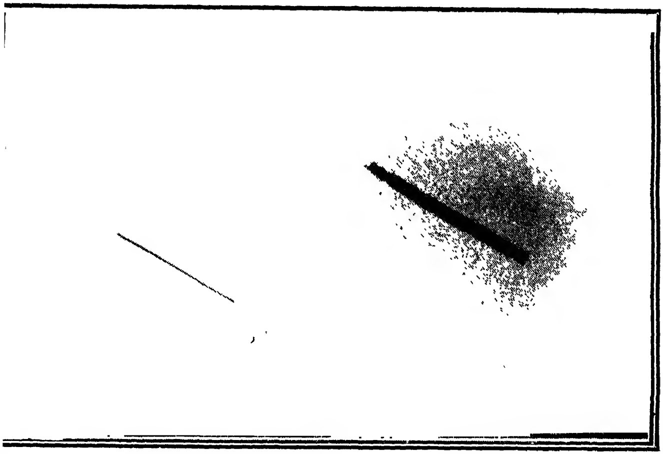
The earth is moving round the sun in the direction of the arrow. When it is at A the sun will appear as if it were among the stars, at Y, but when the earth reaches B it will appear to be at Z. So, as the earth proceeds upon its journey, the sun will appear to be moving continually.

The same experiment can be carried out in a room by fixing up something in the centre and watching it change its position against the walls as you move round it.

That shows us how the sun, which is still, appears to be going round us when in reality we are going round it.

Why is the Sun so Hot?

Whence does the sun obtain his heat? He goes on shining year after year without getting appreciably cooler. Where does it all come from?



THE RAPID MOVEMENT OF THE MOON

These two photographs were taken on *consecutive* evenings. The broad line is the moon and the fine one Jupiter. In the upper photograph a star can just be seen too. Taken with an ordinary camera.

To face page 32

It has been reckoned that if the sun were simply a huge fire it would have burnt out ages ago, so that that explanation will not suffice. Fortunately, however, there is another explanation which seems to fit in with everything that we can observe about the sun's heat.

Have you ever noticed that when india-rubber has been used to rub out a pencil mark it is quite hot? A gimlet which has just been used to bore a hole in a piece of wood is an illustration of the same thing, for if touched it will almost burn the fingers.

These two things show us that heat may be produced by mechanical force. The scientist puts it that the energy expended in moving the india-rubber or in turning the gimlet has been converted into heat.

The Sun is Soft.

The sun is 866,400 miles in diameter, while the earth is only 7918, so that, you see, it is ever so much bigger. Indeed, its volume is over a million times that of the earth. It is not so dense, however, so that a piece carved out of the sun, the size of the earth, would only weigh a quarter of what the earth does. It is therefore not so solid as the earth, but is probably formed of gas; in fact, we may think of the sun as a huge ball of intensely hot gas, far hotter than any earthly furnace.

Everything Heavier on the Sun.

Now when you stand up for a time you feel tired. That is because the matter of which your body is

composed and that of which the earth is formed are attracting each other, or in other words you have weight, and if the earth were twice as big as it is you would be twice as heavy. That is in accordance with the law of gravitation, which applies to the sun just as much as it does here, so that if you lived on the sun, which is so much bigger than the earth, it would attract you more powerfully than the earth does; you would be much heavier there.

A person weighing ten stone on the earth would weigh about 1 ton 14 cwt. on the sun; he would not be able to stand up because his legs would not be strong enough to support him. So, you see, everything on the sun is very heavy, and must be pressing inwards with great force; and as the sun is not a solid incompressible body, but a soft gaseous one, it is gradually being squeezed in, and the force that is being used up in squeezing it is being turned into heat, just as the force that you exert in rubbing out a mark, as we saw just now, is converted into heat.

That, then, explains the heat of the sun, and it has been calculated that the process can go on for many years, so that it will probably be ten million years or longer before the sun is too cold to support life on the earth.

What the Sun is made of.

But what are the materials of which the sun is made?

Many of them seem to be the same as those which we have on the earth, only, of course, things which we

know as solids are gases on the sun because of the intense heat there. There are most of the metals, also carbon, oxygen, hydrogen, and so on. There is one substance which has been named Coronium, known to exist on the sun, but not found as yet on the earth. There used to be another called Helium, but that has now been discovered here.

This statement that we can tell what the materials are of which the sun is formed, and even discover things there which we cannot find on the earth, seems to be almost more than we can believe. Yet the instrument which gives us this startling information is really a very simple contrivance. It is called the Spectroscope, and consists of a little three-cornered piece of glass through which the light from the sun can be viewed. It will be explained more fully in a later chapter, so that it is sufficient to say here that a beam of light from a glowing gas, after passing through the spectroscope, comes out in the form of a band of beautiful colours called the Spectrum, with lines at intervals across it. Each kind of gas has its own set of lines, and if there are several gases the lines belonging to them are all mixed up together. By study, however, they can be deciphered and the separate sets picked out and identified.

That is how the composition of the sun has been found out, and it is still being studied by the same means.

How to find the Sun's Diameter.

Its diameter, as we have already seen, is 866,000 miles. That figure we can check for ourselves.

Get a piece of cardboard an inch wide and bend it to an L-shape so that it will stand up vertically. Then put a book at one edge of a table and your eye close to the opposite edge and place the strip between them so that it just hides the book. Measure then the distance from your eye to the strip and from your eye to the book, and you will then be able to calculate the width of the book in this way.

As the distance from eye to strip is to the distance from eye to book, so is one inch to the width of the book. It is just a little simple proportion sum.

Now you can calculate the diameter of the sun in just the same way.

A strip of paper one inch wide pasted on a window will, you will find, just hide the sun if you stand nine feet away from it.

The distance we know to be 92,900,000 miles; therefore a simple proportion sum will tell you the diameter. How the distance is found we shall see in another chapter.

What we see when we look at the Sun.

The round white disc which we can see so plainly when we look at the sun through a smoked glass is called the Photosphere.

Around that is a layer of crimson fire with tongues

of flame leaping outwards which can only be seen during an eclipse or through a spectroscope. This layer is called the Chromosphere, and the tongues of flame Solar Prominences. Outside them is a sort of halo of faint grey light known as the Corona, which can only be seen during an eclipse.

The reason the Chromosphere, Prominences, and Corona cannot be seen ordinarily is that the glare of the Photosphere entirely overpowers their fainter light.

Sunspots.

At times dark spots appear. Sometimes they are small, and can only be seen through a telescope, but at others they can be easily viewed with the naked eye, through a piece of smoked glass, or when the bright light of the sun is partly obscured by mist. They do not last long, and they change a great deal, but they last long enough for us to see that the sun is rotating upon an axis at the rate of about once in twenty-five days.

Exactly what the spots are is not known with anything like certainty, but they are believed to be patches of cooler matter than the rest of the sun rushing downwards into the body of the sun; possibly the downfall of those great tongues of flame, referred to just now, called Prominences.

CHAPTER IV

TIME

WE have seen that the other stars are all continually circling round the Pole Star, and that they complete this circle once in about twenty-four hours.

The sun is doing the same thing, only as Polaris is not visible when the sun is, we do not notice the fact.

He rises in the east every morning, passes round by the south and sets in the afternoon or evening in the west, following just the same curve as the stars do, namely, a curve of which the Pole Star is the centre.

In the sun's case the speed is slightly modified by the fact that while he and the stars move rapidly from east to west, he, as we know, is slowly moving among the stars from west to east. The result of that is that he appears to take slightly longer than they do to complete the circle.

These different motions are very confusing at first, but quite simple when once we understand them.

All motion of any body must be *in relation to* some other body. I travelled this morning in an electric tramcar; while I was sitting reading my paper, I was stationary *in relation to* the tramcar, but I was moving *in relation to* the houses in the street, at a rate of, say, ten

miles an hour. When I got up to get out I walked from the front of the car to the back while the car was still in motion; therefore at that time I was moving, say, two miles an hour *in relation to* the car; yet the car was moving ten miles an hour *in relation to* the houses; further, since my movement was in the opposite direction to that of the car, I was then moving *in relation to* the houses at eight miles an hour, that is, ten less two.

That illustrates very well what we are talking about. Let us think of the houses as representing the earth, the car the stars generally, and myself the sun.

Now read the following twice over, using first the upper words and the second time substituting the lower ones for them. It will then be quite clear why the sun's daily motion seems slower than that of the stars.

The speed of the $\dfrac{\text{(car 10)}}{\text{stars}}$, less the speed (in the opposite direction) of $\dfrac{\text{myself in it (2)}}{\text{the sun among them}}$, gives the speed at which $\dfrac{\text{I was passing the houses (8)}}{\text{the sun seems to travel round the earth}}$.

Now let us see how this works out. The sun, as we saw in the last chapter, travels right round the Zodiac from west to east in one year precisely. Therefore, in one year, he circles round from east to west once less than the stars do. They move round 366¼ times, while he moves round 365¼ times.

The Solar Day.

It is this apparent daily motion of the sun that gives us our day and night. A solar day of twenty-four hours is the time which the sun takes to move from any one position, right round and back to the same position again.

Another Observation.

It is easy to observe this motion of the sun. Drive a stout needle into a piece of wood, fix it somewhere where the sun can shine upon it so as to throw a shadow of the needle upon the wood ; rule or cut a fine line in the latter and notice the exact time when the shadow falls upon it. Take a look at it every day, if you can, and you will make a discovery which will possibly surprise you.

You will expect to find the shadow always on the mark at the same time, and will begin to think your watch wants regulating, for it will appear, judged by the shadow, to be either gaining or losing. *It will be the sun, however, which is wrong.*

Movement of the sun irregular.

The idea that a sundial always shows the correct time is erroneous. The sun travels through the Zodiac more quickly at some times than it does at others,* and so the length of the day varies slightly too.

The variation in one day is slight, but the difference goes on accumulating day after day, until it amounts to

* The reason of this is explained on pages 55 and 56.

about a quarter of an hour, then it slowly gets right again, only to become as much wrong *the other way.* Part of the year the true or "apparent solar time," as it is called, is in advance of the clock and part of the year behind it.

The *average* length of the day throughout the year, however, is exactly twenty-four hours.

Since it varies so much as that, apparent solar time is useless for regulating our lives by. Just fancy how it would upset railway travelling if the watches and clocks had to be continually altered.

Mean Solar Time.

Astronomers have therefore invented an imaginary sun called the "mean" or average sun, which is quite uniform in its motion, and an artificial time called "mean" time, in which every day is exactly twenty-four hours long. That is the time which we use in the ordinary affairs of life; for that reason it is also called "civil" time. The difference on any day between apparent and mean solar time is called the "Equation of Time." (The "Equation of Time" for each day is given in "Whitaker.")

Sidereal Time.

Astronomers use another measure of time, the Sidereal day. This is the time which any star takes to move from any position, right round and back again; and since, as we have seen already, the stars move a little quicker than the sun, the sidereal day is a little

shorter than the solar day. It is, in fact, 3 minutes 56 seconds less, being 23 hours 56 minutes and 4 seconds of solar time. Since it depends solely upon the rotation of the earth, which is quite uniform and steady, sidereal time is not subject to variations like true solar time.

Observation for Sidereal Time.

When you have made the small telescope which I will describe in a later chapter you will be able to test the difference between mean and sidereal time for yourself, but it will be interesting for me to describe here how you can do it. First of all you fix up your telescope, if possible at a window facing south, so that you can "sight" it upon a star, low down on the southern horizon.

Then watch the star pass across the field of view of the telescope and notice exactly the time at which it crosses the vertical "wire" in the telescope.

Now when you do this you must take the domestic authorities into your confidence and arrange with them that the instrument shall not be touched until the next night. Then watch again, and you will find the star will cross the wire just about four minutes earlier. Now your watch is regulated to keep solar time, and this observation therefore shows that the sidereal day is shorter than the solar day by about four minutes. If we had very accurate appliances we should find the sidereal day to be 23 hours 56 minutes 4 seconds.

The reason why, for this purpose, we should choose a

star which is low down in the south is because those in that position are the farthest away (of all those which we can see) from the Pole Star, and therefore the circle which they appear to describe is the largest possible, and since they all complete the circle in the same time those which appear to move in the largest circle appear to move fastest, and are therefore easiest to measure.

How the Exact Time is found.

We can now look at the methods by which astronomers ascertain the exact time. They have a certain mark, and they watch the exact moments when the sun and certain well-known stars appear to pass that mark.

The Meridian.

This mark is an imaginary line drawn across the sky in an exactly north-and-south direction, from the southern horizon through the point exactly overhead to the northern horizon; and it is called the Celestial Meridian or, more briefly, the Meridian.

Or it may be described as an imaginary line across the heavens *exactly over* the earthly meridian which we see marked upon the maps.

All the heavenly bodies appear to cross this line once a day, or in the case of those stars which are so near the Pole Star that they never set, twice a day. The passing of this line by a body is called a "transit."

The Transit Instrument.

The difficulty is to draw this line on the sky in such a way that it can be clearly seen. One way would be to have a metal semicircle with its ends fixed in the earth and passing over the observer's head, but that and all similar devices have the defect that the eye focusses itself naturally upon the object at which it is directed, and cannot be focussed upon a distant and near object at the same time; if we try to do so, one of the two will be indistinct.

This difficulty, however, can be got over perfectly by using a telescope mounted in a certain way. It is supported upon two strong pivots, one on each side, which work in sockets resting upon two massive stone pillars fixed upon deep foundations.

It is free to move like a see-saw; indeed, it can be turned right round in a complete circle; but it cannot be moved a hair's-breadth to either side. It is so placed, too, that it points exactly north and south when it is horizontal, and when it is turned end upwards it is *exactly* vertical. Just behind the lens nearest the eye (the eyepiece, as it is termed) there is a vertical thread of spider's web, and it is easy to see that if such a telescope be turned to any part of the sky, that thread of spider's web will look to the observer like the meridian actually drawn across the heavens. It is then easy to tell within a fraction of a second when a star "transits" the meridian.

Time

The Two Noons.

Noon by apparent Solar time is the moment when the sun "transits" the meridian. Noon by Sidereal time is the moment when the "first point of Aries" crosses it. The two coincide on March 21st.

By observing the transits of certain stars whose positions are known very exactly astronomers can tell the sidereal time within one-tenth of a second; they can then easily convert it into mean solar time for the use of the public.

The Sidereal day begins at noon, and goes on through 24 hours—not 12 hours twice over as an ordinary clock shows; therefore the hour before noon by sidereal time is 23, not 11.

Astronomers have for their own use a special way of reckoning mean solar time, which they call Astronomical time. They begin the day at noon instead of at midnight, and go on counting the hours up to 24. Thus their 1st of January begins at 12 (noon) on the ordinary 1st of January; and what we call 10 o'clock A.M. on the 2nd they call 22 o'clock on the 1st.

How Scouts can tell Time by the Stars.

Although it needs a very perfect instrument to tell the time exactly, we can judge the time approximately for ourselves any fine night.

A line drawn through one of the stars of the Plough, the Pole Star, and one of the stars of the constellation Cassiopeia (all of which are clearly shown in Fig. 2)

passes near the first point of Aries, so that when that line is exactly vertical, with the Plough underneath the Pole Star, it is noon by sidereal time. When it is horizontal, with the Plough to the right, it is 6 o'clock; vertical, with the Plough overhead, 12 o'clock; horizontal, with the Plough to the left, 18 o'clock, and the intermediate times in proportion; and by holding up a book or stick or anything with a straight edge so that all these stars are seen just touching the edge, it is easy to judge within a little what the sidereal time is.

But how are we to convert that into solar time? It is not difficult.

Remember it is mean solar time that we want, and on March 23rd (not 21st) MEAN solar time and sidereal time are nearly the same. The next day, since the sidereal day is shorter by 3 minutes 56 seconds, if we deduct that amount from sidereal time we get the solar time.

The next day we must deduct twice as much, and so on. A rough, easy way of doing this is to reckon the number of calendar months since the 23rd of March and multiply by 2 hours. Then take the number of odd days and multiply by 4 minutes, and add the two together. That will give you the amount to deduct from the sidereal time to get solar time. This is a very interesting exercise in practical astronomy.

To make this quite clear I will give you an instance. On January the 20th I looked at the sky, and from the position of the Plough I judged the sidereal time to be 5.30. Now what would that be in solar time?

From March 23rd to December 23rd is 9 months, and from December 23rd to January 20 is 28 days.

9 times 2 hours	=	18 hours	0 minutes.
28 times 4 minutes	=	1 hour	52 minutes.

Deduct 19.52 from 5.30=9.38, which will be the approximate solar time. Of course when the time to be deducted is more than the time which you have to take it from, the latter must be increased by 24 hours.

The exact equivalent in solar time for 5.30 sidereal time on the 20th January was 9 hours 36 minutes and a third, so that this simple method of reckoning is not far wrong.

Greenwich Time.

Since the time which we use is based upon the time when the sun crosses the meridian, and since every place has its own meridian, it follows that the time will vary in different places. For example, the sun's daily movement is from east to west, and so it will cross the meridian of a place in Cornwall, say, some time after it has passed the meridian of Greenwich. Now it would be a great nuisance if every town in England had its own time, so we all use Greenwich time.

The astronomers there keep their clocks very accurate by continual observations of the stars, and every day they communicate by telegraph the exact Greenwich mean solar time to all parts of the country.

How Greenwich sets the Time for the World.

And not only do we in England use Greenwich time. In all the civilised countries of the world (except France and Russia) the standard time which is used on the railways and for the ordinary affairs of life is either Greenwich time or an exact number of hours in advance of or behind it. In Belgium, Holland, and Spain, for example, the time used is exactly the same as ours; in Germany and Austria it is exactly one hour in advance; in the eastern part of the U.S.A. it is exactly five hours behind.

A Transit Circle

Notice the massive supports, also the large circles for showing the inclination of the instrument and the microscopes for reading them.

To face page 40

CHAPTER V

THE WANDERERS

WHEN the ancient astronomers first studied the stars they found that there were several very bright ones which did not behave in the same orderly regular way that the others did. There were five of these altogether, and they eventually received the name of Planets, or Wanderers.

Each of them also had a separate name given to it, and so they came to be called Mercury, Venus, Mars, Jupiter, and Saturn.

These five have been known since very remote times, but we now know there are three others. One of these is the Earth itself, and the others are Uranus and Neptune, which are so faint that they escaped notice until comparatively recently.

How to Find the Planets.

But before we can look at these bodies we must know where to find them.

In the first place they are always somewhere in or near the Zodiac.

Mercury is never far from the sun, and so can only be seen just before sunrise or just after sunset, while it

is often too near the sun to be visible at all, the fiercer glare of the sunlight completely overpowering the fainter light of the planet. Mercury is very rarely seen.

Venus also keeps near the sun, but not so near as Mercury. Like him she is lost to view at times through being immersed in the sun's glare, but when she is visible there is no mistaking her, for she is the brightest body in the whole sky, excepting of course the sun and moon. She shines with a lovely clear bluish light.

She never rises more than about four hours before the sun or sets more than four hours after; but when at her brightest she can be seen sometimes with the naked eye in broad daylight.

Neptune is so far off that he is invisible except through a telescope. Uranus, for the same reason, is only just within the range of naked-eye vision. That leaves three others, Jupiter, Saturn, and Mars.

These may be visible at any time and at any place along the Zodiac, but they all have times when they are invisible, for, like Mercury and Venus, they occasionally get too near the sun and are lost in his brilliant light.

Their brightness varies, but Jupiter, as befits his size, is always a noticeable object when he happens to be about.

Saturn is much fainter, about like one of the brightest of the fixed stars, while Mars when at its best is a very bright flaming red dot in the sky, but its light is subject to considerable variation.

The Need of a Good Almanack.

The best way to find them is to look in an almanack such as "Whitaker," and see the times when each one rises, "souths" (that is, crosses the meridian), and sets.

Then it is easy to tell just about where to look for them. For instance, there are at the time of writing two very bright stars opposite my house every evening about seven. I know they are not fixed stars because they are gradually moving in relation to the other stars near them.

What can they be? If I look up my almanack I find that Mars "souths" to-morrow at 6.56 and Saturn at 7.21, and as my window faces south I know that the two strange stars must be those planets.

Moreover, as Mars sets the earlier of the two I know he must be the more westerly of them.

Or if I want to have a look at Jupiter I can turn up his time-table; I shall find that he rises to-night at 1.18 and "souths" at 7.4 to-morrow morning. From that I know that I should, clouds permitting, be able to see him, say, at 6.0 a.m. to-morrow a little to the east of "south." The almanack also tells you the constellations which the planets are in at different dates.

When you have found the planets it is quite easy, with an occasional glance at the sky and perhaps an occasional reference to the almanack, always to keep in touch with them, and to know within a little where to look for them. When you can do that it is very interesting to watch their movements.

The Curious Motion of the Planets.

Of course they pass across the sky from east to west every day, just as the sun and stars do, and for the same reason, namely, that the earth is spinning on its axis; but they have other motions as well.

Sometimes they move among the stars from west to east as the sun does; at other times they move from east to west; and there are periods when they seem to be standing still.

Tycho Brahé.

How can these curious motions be explained? That is a question which people tried to answer for ages. The ancient Chinese, Chaldeans, and Greeks tried to explain them; many ingenious and complicated theories were formed, all of which, however, failed to give a satisfactory explanation. This went on until in the sixteenth century, about the time of our Queen Elizabeth, there arose a very clever and painstaking Danish astronomer named Tycho Brahé. He came to the conclusion that until then people had gone the wrong way to work, by inventing theories on insufficient information, and he decided that the proper thing to do was first of all to watch very carefully and measure the movements of the planets with the utmost possible accuracy; then he thought the real explanation could be found.

So, with the assistance of the King of Denmark, he set up an observatory, and, although it was before the time of the telescope, he was able, being a clever

mechanic, to devise instruments which enabled him to accumulate a great mass of precise information about the planets, particularly about the movements of the planet Mars.

John Kepler.

When he died his records passed into the possession of a man who had been one of his assistants, John Kepler by name, and then the wisdom of Tycho Brahé was proved; with these records before him Kepler was able to discover the true principles upon which the solar system works.

It had been suggested before then that the sun was the centre of the system and that the planets were revolving round it, but Kepler proved that it was so; he also determined the distances of the planets from the sun; found their paths were not circles but ellipses; reckoned the speed at which they move; found that the speeds and the distances from the sun bore a certain relation to each other.

All these things were not guesswork, but were worked out from, and tested by, the actual observations of Tycho Brahé.

These discoveries are all summed up in the three laws of planetary motion, or Kepler's Laws, as they are often termed.

Kepler's First Law.

The first one states that the orbit of every planet is an ellipse with the sun at one of the foci. To understand this we must know what an ellipse is.

How to Draw an Ellipse.

It is commonly called an oval, and the easiest way to draw it is this. Fix two pins in a drawing-board a little distance apart; put a loop of string over both of them, insert the point of a pencil in the loop, and, keeping it tight, move the pencil round.

The pencil will then describe an ellipse, and each of the pins will be at one "focus" (plural "foci"). If the foci are very near together the figure is very nearly a circle.

The Planets' Orbits are almost Circles.

The orbits of the planets are almost circles, so much so that if they were drawn accurately as illustrations in this book no one would be able to tell by looking at them that they were not circles.

Still the fact remains that they are not true circles, and that the planets are therefore nearer to the sun at some times than they are at others. We can see this in the case of the earth, for on the 1st of January the sun looks larger than it does on the 1st of July, showing that we are nearer to it on the former date.

Kepler's Second Law.

The second law of planetary motion states that the speed at which a planet travels is such that a line from it to the sun (known as the Radius Vector) will sweep over equal areas in equal times.

This sounds alarming, but it will be understood quite easily from Fig. 4. The oval represents the orbit of a planet such as the earth, and the point near the centre is the sun. In passing from A to B a line from the planet to the sun would sweep over the shaded area 1, while in passing from C to D it would sweep over 2. Now if it takes the planet a certain time to move from

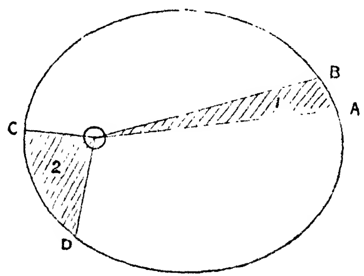


FIG. 4. EQUAL AREAS IN EQUAL TIMES

An imaginary line from a planet to the sun sweeps over equal areas in equal times. Let us imagine the oval (or ellipse, to give it its proper name) to be the orbit of a planet, and the two triangular shaded areas to be equal. Then the planet will take exactly the same time to pass from A to B that it will from C to D. The speed of a planet is continually varying throughout its orbit. The orbit of every planet is more nearly a circle than this.

A to B and the same time to move from C to D the two areas will also be equal, "equal times equal areas" being the rule.

Why the Movement of the Sun varies.

Therefore when the earth is near to the sun, as we have seen it to be in January, it must move more

quickly so as to be able in any given time to sweep over the same area that it would do during the same time in July when it is farthest away. If the speed of the earth varies it follows that the apparent motion of the sun must vary too; that is why the sun does not tell us the true time.

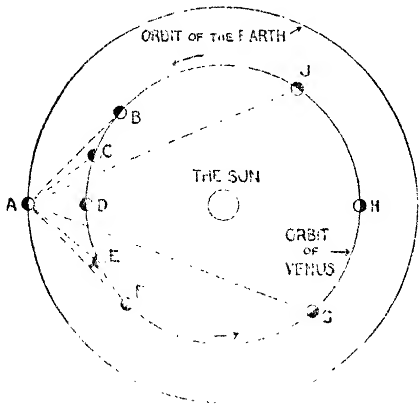


FIG. 5. APPARENT MOVEMENTS OF AN INFERIOR PLANET—ONE WHOSE ORBIT IS INSIDE THAT OF THE EARTH (VENUS, FOR EXAMPLE)

A and B and A and F indicate the relative positions of the two bodies when Venus appears farthest from the sun.

When Venus is at C and G it seems to be moving towards the sun, and at J and E away from the sun. At D and H it will be invisible from the earth.

Position A and B is called Greatest Eastern Elongation, A and F Greatest Western Elongation.

Position A and D is called Inferior Conjunction, and A and H Superior Conjunction.

We can see here why an inferior planet is never seen far from the sun.

Kepler's Third Law.

The third law amounts to this. The earth's mean distance from the sun is in round figures 93,000,000 miles, and it completes one revolution in 365¼ days.

Suppose there were another planet which took 687 days to complete a revolution, we could calculate its

distance from the sun by a simple proportion sum thus—

$365\frac{1}{4}^2 : 687^2 :: 93^3 :$ the answer

The *cube root* of the answer will be the distance of the other planet in millions of miles, and if you like to try it

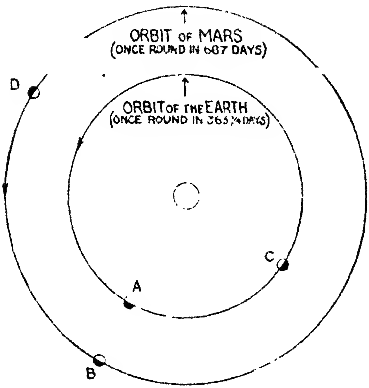


FIG. 6. THE APPARENT MOVEMENTS OF A SUPERIOR PLANET—ONE WHOSE ORBIT IS *OUTSIDE* THAT OF THE EARTH (MARS, FOR EXAMPLE)

When Mars and the earth are situated as at A and B Mars is said to be "in opposition," that is, we see it in the opposite direction to the sun.

When they are placed as at C and D Mars is said to be "in conjunction," which means that Mars and the sun are in the same direction.

Owing to the earth's movement round its orbit the sun appears to travel among the stars from west to east, and when near conjunction Mars must appear to do the same, and for the same reason. That is called *Direct* motion.

At or near opposition, however, we overtake Mars, and pass him on our right hand while the sun is on our left, and consequently Mars, as seen against the background of the stars, appears to be going *backward*, from east to west. That is called *Retrograde* motion.

At the positions where the motion changes from Direct to Retrograde and vice versa the planet appears for a short time to be stationary.

you will find that the final result will be about $141\frac{1}{2}$ millions.

Now, as a matter of fact, there is a planet which goes round the sun in 687 days—it is Mars—and its distance from the sun is $141\frac{1}{2}$ millions.

That illustrates Kepler's third law, which says that "the square of the time of one revolution is in proportion to the cube of the mean distance," and if you care to try it with any of the other planets you will find that it will work equally well with them.

Sir Isaac Newton.

Kepler discovered his three Laws simply from observation; it was the great Englishman, Sir Isaac Newton, who discovered the reasons for them. He, too, put his discoveries into the form of short concise statements which have been named Laws; we need only trouble ourselves with two of them—the Law of Universal Gravitation and the First Law of Motion (not planetary motion, that was Kepler's).

Law of Gravitation.

The Law of Universal Gravitation tells us that every particle of matter throughout the universe (not merely on the earth) attracts every other particle. Thus the earth and sun, each a mass of particles all acting together, attract each other, and their power of attraction is in proportion to their "mass" or the amount of "stuff" in them.

Thus we are able to find out the mass (or we might in a sense call it "weight") of the heavenly bodies by calculating how hard they pull at each other. The attractive power also depends upon the distance of the bodies apart; it diminishes in proportion as the *square of the distance* increases.

First Law of Motion.

The First Law of Motion states that if a body be in motion it will continue to move at the same speed and *in a straight line* unless some outside force compels it to change. The manifestation of this law we often call Momentum.

These laws explain how the motion of the planets is kept up, but they do not explain how they were started.

If they be once given a push, gravity and momentum will do the rest, but how they were set going no one can tell; that belongs to the infinitely remote past, which the mind of man is entirely unable to comprehend.

Why a Planet Keeps to its Orbit.

Let us imagine, however, that we can see a planet just being launched on its journey by some unseen power. It is at A (Fig. 7) and is being pushed off in the direction of the arrow, while the sun is at B.

As it proceeds towards C the sun is partly pulling it back—acting as a sort of brake upon it—and partly pulling it to the right.

Thus it curves round to D, and since the tendency of a moving body to keep in a straight line diminishes as the speed diminishes, so the diminishing speed permits the sun to pull it round through E to F. As soon as it passes E it begins to curve back *towards* the sun, and so the sun's attraction, instead of retarding it, pulls it along faster. On it comes through G to H, getting faster and faster all the time, until it is much nearer the sun than

it was. The sun's power increases as it draws nearer, but it is unable to pull it to itself as the speed has increased too. The sun is strong enough, however, to keep it from running away altogether, so it sweeps

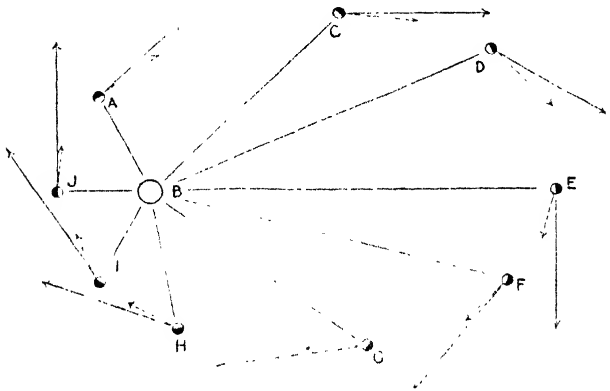


FIG. 7. HOW "MOMENTUM" AND THE ATTRACTION OF THE SUN, ACTING TOGETHER, KEEP THE PLANETS IN THEIR ORBITS

B is the sun. A, C, D, etc., represent the planet in various positions.

In each position shown the momentum is urging the planet in the direction of the long arrow, while the sun's attraction is pulling it in the direction of the radiating line. The planet is influenced by both forces, so it takes a course between the two, as indicated by the dotted arrow. The forces are, of course, acting continually, and not simply at the positions shown, and so the planet describes an ellipse.

round through I to J to the starting point A, whence it starts upon the same journey once more. Thus these two forces acting together and just balancing each other keep the planets going in their regular orbits;

and since there is no friction or other resisting force it seems as if this will go on for ever.

Why the Orbits are not Circles.

The exact shape of the ellipse depends upon the force that started the planet, its speed and its direction, and the distance of the starting point from the sun. Certain combinations of these would cause a planet to move in a circle, but the probability of such a combination occurring must be millions to one against; therefore no known planet has a circular orbit.

Why do the Planets keep near the Zodiac?

Why, it may be asked, do the planets as well as the sun and moon always appear to lie along that particular strip of sky which we call the Zodiac? It is because they all move in nearly the same plane.

If you lay a number of balls on a table and place your eye at the edge of the table you will see all the balls in a row, and no matter how they may be moved about on the table they will still be in a straight row. Now the surface of that table would be the "plane" on which they move. Of course the earth does not roll about on a table, but it behaves exactly as if it did.

We must therefore imagine a perfectly flat surface passing through the centre of the sun and through the centre of the earth, and the earth always keeps on that plane. It never rises above it, nor sinks below it.

A more perfect illustration is this: imagine two balls weighted so that they are exactly half the weight of water. Then place them in water and they will float exactly half immersed; their centres will be level with the surface. The two balls will then represent the sun and the earth, and the surface of the water will represent the plane in which the earth revolves. That plane is known as the "plane of the ecliptic," and if we imagine it continued until it cuts the sky it will give us a line drawn right round the sky among the stars.

That line is the ecliptic, and if we think of how one floating ball would look if seen from the other, while moving, we shall see why that line is drawn for us on the sky by the apparent movement of the sun.

If now we put some other balls into the water they will not quite illustrate the movement of the other planets, since each of the planets revolves on a surface or plane of its own, but the inclination of the other planes to that of the ecliptic is so little that the planets are never seen very much above or below the ecliptic.

It is by measuring their distance above or below the ecliptic that we are able to tell the plane in which they move.

The Earth's Little Brothers.

It had been noticed that the planets seemed to be arranged at such distances from the sun as to follow a regular law, except for a space between Mars and Jupiter, where there appeared to be one missing.

This puzzled astronomers, until on the first day of the nineteenth century a very faint star was noticed which seemed to be a planet. A little watching proved that it was really so, and thus a new member was added to the sun's family. Moreover, it was found that its orbit lay between those of Mars and Jupiter, and as, since then, seven hundred others have been discovered it turns out that the space which was thought to be empty is really quite crowded. The size of these planets is quite tiny, however, varying from four hundred odd miles in diameter down to a few miles.

At first it was difficult to find these tiny dots of light, for they were lost among the host of small stars, and the fact that they were moving like planets was very difficult to detect, but they are now caught in shoals, almost, by means of photography. A large telescope is converted into a huge camera, by taking away the lens nearest the eye and putting a photographic plate there instead; and a long exposure is given. The telescope is moved by clockwork, so as to follow the stars in their movement across the sky, and so they come out as sharply defined points, but the planets, having a motion of their own different from that of the stars, appear as streaks. Thus it is quite easy to pick out the latter.

Special reference must be made to one tiny planet called Eros. It is so small that upon its surface the Isle of Wight would be a continent and its orbit lies mainly between that of Mars and our own, yet it is so

very elliptical that at times it crosses the orbit of Mars and goes outside it. There is no fear of collision between the two, however, as they are on different planes. The reason why Eros comes in for special

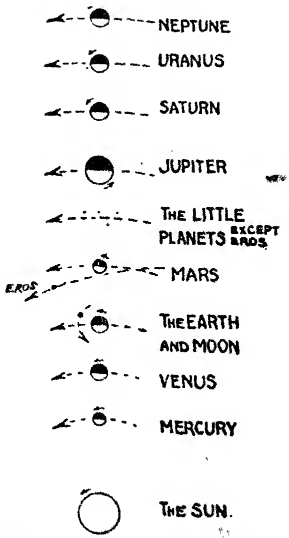
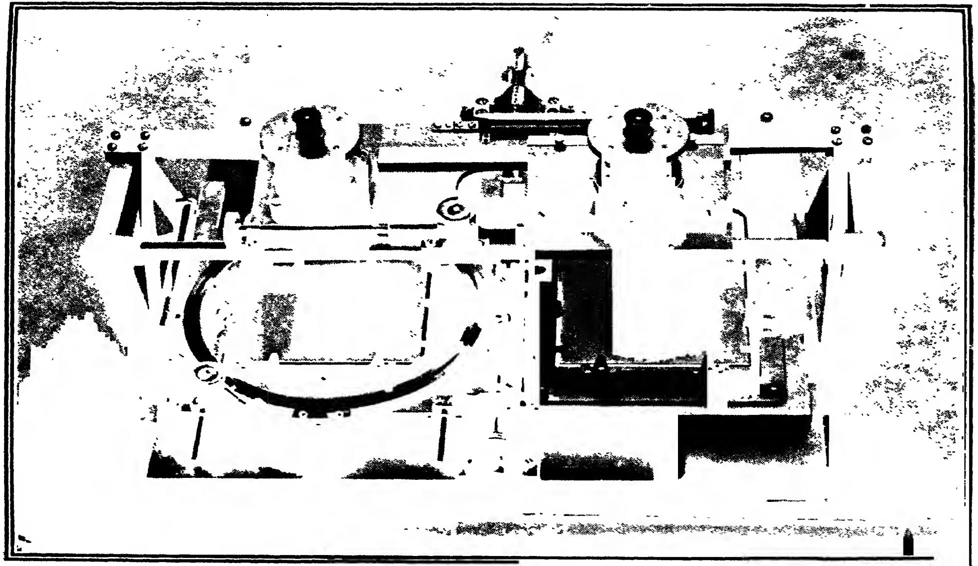


FIG. 8. PLAN OF THE SOLAR SYSTEM, TO SHOW THE WAY THE BODIES ARE MOVING

Arrows show the direction of movements as they would appear *if seen from the Pole Star.*

N.B.—This diagram does not show the sizes and distances in the correct proportion (for these see table opposite).

mention is because it is our nearest neighbour (except the moon) and it will probably provide the most accurate means of telling the distances of the planets, as will be explained in a later chapter.



By kind permission of *Messrs Troughton & Simms*

ASTROGRAPHIC MICROMETER

This is for comparing two astronomical photographs and detecting and measuring any slight difference in the position of a star. A very minute movement can be discovered by this wonderful instrument

To face page 64

TABLE OF FACTS ABOUT THE SUN AND PLANETS

For the direction of the movements see Fig. 8.

	Mean Distance from the Sun in Millions of Miles.	Times of Revolution round the Sun in terrestrial Days.	Time of Rotation.		Diameter in Miles.	Volume in Proportion to the Earth.	Density in Proportion to the Earth.	
			Hrs.	Mins.				
The Sun . .	—	—	607	48	866,400	1 310 000	·25	
Mercury . .	36	88	88[1]		3030	·06	2·23	
Venus . .	67	225	225[2]		7700	·9	·86	
The Earth .	93	365$\frac{1}{4}$	23	56	7918	—	—	One satellite.
Mars . . .	141$\frac{1}{2}$	687	24	37$\frac{1}{3}$	4230	·15	·72	Mars has two very small satellites very close to him. One of them revolves round him every 7 hours, that is, *three times a day.*
Jupiter . .	483$\frac{1}{4}$	4333	9	56	86,500	1309	·24	Jupiter has eight satellites.
Saturn . .	886	10,759	10	14$\frac{1}{2}$	71,000	849	·13	This planet is surrounded by three thin flat rings. It also possesses ten satellites.
Uranus . .	1800	30,687	9	30	31,900	59	·22	Uranus has four satellites.
Neptune . .	2800	60,127	(unknown)		32,900	103	·2	Neptune has one satellite.
	Mean Distance from the Earth in Miles.							
The Moon .	230,000	—	—		2163	·02	·61	

[1] Some astronomers think Mercury rotates in about 24 hours, but the majority consider the period to be 88 days.
[2] This also is thought by some to rotate in about 24 hours, but the evidence for 225 days is certainly quite as strong.

CHAPTER VI

MEASURING THE UNIVERSE WITH A YARD MEASURE

IF there is one thing more than another that puzzles the ordinary mortal it is the fact that astronomers can measure the distance away of the sun, the other planets, and even the stars. It certainly seems, at first sight, a very wonderful thing to do, for there is so little to go upon; they all look as if they were equally far away and the only thing we can see is that they seem to change their positions more or less.

Yet the methods by which it is done are in themselves quite simple, and anyone with a slight knowledge of geometry and a shilling almanack can calculate some of them approximately for himself.

The Astronomer's Friend—the Triangle.

The secret of the whole thing is a certain virtue possessed by all triangles. If of any triangle we know the size of two angles we can reckon the size of the third one, also the *proportionate* lengths of all the sides. Then if we are able to measure the actual length, in feet, yards, or miles, of any one of the sides we can calculate the actual lengths of the other two.

The Size of an Angle.

First of all, however, we must be quite clear as to what is meant by the size of an angle. Whenever two straight lines meet they form an angle, and when we state that an angle is of a certain size we do not refer to the length of the lines or anything of the sort, but to the amount of the inclination of the lines toward

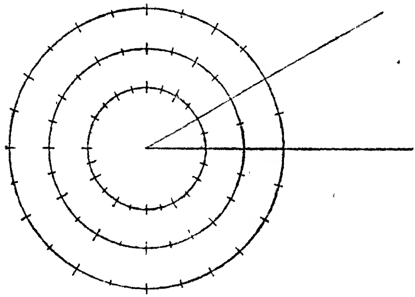


FIG. 9. HOW AN ANGLE IS MEASURED

each other. That inclination we usually express by stating that the angle is of so many "degrees."

In Fig. 9 the two lines form an angle. Now suppose we take a pair of compasses and, as shown in the diagram, describe a circle of any convenient size. Let us then divide the circumference of that circle into 360 equal parts, and the number of such parts which lie between the two lines will be the number of degrees in the angle.

The size of the circle does not matter at all, because whatever its size may be, so long as it is divided into 360

equal parts, the same number of those parts will be contained between the lines. The angle shown is 30 degrees, and I have drawn three circles each of which is divided into the same number of parts, so as to make it quite clear that whatever size of circle we use the result is just the same. Each degree is further divided into 60 minutes and each minute into 60 seconds.

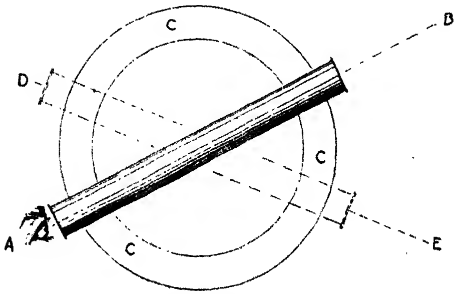


FIG. 10. HOW A THEODOLITE WORKS

A B = first position of telescope; D E second position of telescope; C C C graduated circle which tells the size of the angle between A B and D E.

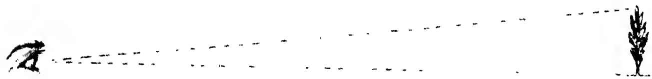
We must understand, too, that light, unless there is some special reason to the contrary, always travels in a straight line, and consequently when we see a distant object we may know that we are looking along a straight line from the object to our eyes.

Angular Measurement.

Suppose, then, I have a small telescope such as surveyors use, called a Theodolite, and that I first of all

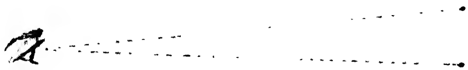
sight it upon a distant tree, its position will indicate the direction of a straight line from the centre of the instrument to the tree. Then, if I turn it round and sight it upon, say, a telegraph pole, I shall get the direction of that also, and by means of the graduated

FIG. 11. EXAMPLES OF ANGULAR DISTANCES

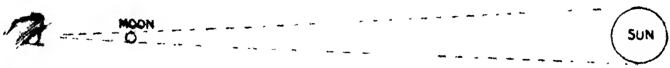


The apparent size of an object is the angular distance between its extreme points. The eye unconsciously measures the angle between the rays of light from the top and bottom of a distant tree, for instance.

Two stars may be very far apart in reality, but by angular measure be quite close.



Here we see two stars much nearer together than those above, but by angular measure farther apart.



The sun is really much larger than the moon, but by angular measure they appear to be about the same size.

circle which forms a part of the instrument I shall be able to read off the size of the angle between the lines (see Figs. 10 and 11). I shall then know the exact direction of the tree in relation to the pole and *vice versâ*, or, to use another expression, I shall have found the "angular distance" between them.

Let us Measure the Distance of Venus.

Now I am not merely going to describe the method by which the distances of the planets can be found, but I will ask you to join me in calculating the distances of two of them. The results will only be approximate, but they will show "how it is done," as conjurers say, and the only difference between what we do and what astronomers do is that our calculations utilise the main idea of the method only, whereas they take account of a number of other considerations, which are minute in themselves, but which affect the accuracy of the result. Moreover, our working will only be rough and ready, whereas they would take the most elaborate care.

We will take Venus and Mars, one inner and one outer planet.

I see from "Whitaker" that on the 14th May, 1910, Venus crossed the meridian at 9.6 a.m. and the sun crossed at 3 minutes 49 seconds (say 4 minutes) before noon (mean solar time). Therefore Venus was in advance of the sun by 2 hours 50 minutes. She had been gradually getting farther away from him, but after the 14th she began to get nearer again; therefore she must, on that date, have been in the position known as "greatest eastern elongation." Now turn to Fig. 12.

In that diagram I have shown the earth with a short line projecting, representing a transit instrument pointed to the sky, and I have indicated by an arrow the direction in which the earth is turning.

At 9.6 that transit instrument pointed to Venus; by 11.56 (about) the rotation of the earth had carried it round until it pointed to the sun. In one day the rotation carries it round a whole circle of 360°; how many degrees, then, did it move through in that interval of 2 hours 50 minutes?

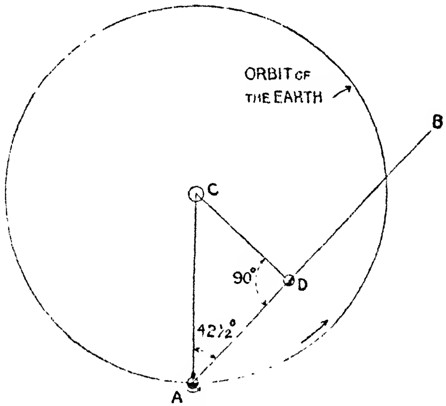


FIG. 12. DIAGRAM FOR CALCULATING THE DISTANCE OF VENUS

The distance from:—

Line A B = Earth to Venus.
,, D C = Venus to sun.
,, C A = Earth to sun.

Now 360° in 24 hours is 15° in 1 hour, 7½° in half an hour, and 5° in 20 minutes. In 2 hours 50 minutes, then, that transit instrument moved through 42½°; therefore, Venus must be somewhere along a line inclined at 42½° to the direction of the sun, that is, along the line A B. Further, if we examine the diagram, we shall see that when Venus is at its greatest apparent

distance from the sun, a line joining Venus and the sun must be at right angles to A B.[1]

Therefore Venus must be at D, and the diagram will be an accurate plan *to scale* of the positions of the three bodies.

The three sides of the triangle A D C will then represent their distances from each other, and if the lines A C and D C be measured they will be found to be in the proportion of 64 to 43.

That will be the proportion of the earth's distance from the sun, to Venus' distance from the sun on 14th May, 1910.

Now the mean distance of the earth from the sun is in round figures 93,000,000 miles, so, by a simple proportion sum, we get—

64 : 43 : : 93 (million miles) : 63 (million miles).

The distance of Venus from the sun on the 14th of May, 1910, was, then, according to our calculations, 63,000,000 miles, and as the mean distance as calculated by astronomers is 67,000,000 we are not far out, considering that we have only taken a few minutes over the work and worked it roughly.

Let us reckon the Distance of Mars.

Now let us try an outer planet, Mars.

On September 23rd, 1909, Mars was "in opposition," that is, all three bodies were in a line. Therefore the

[1] If you are in any doubt about it redraw the diagram to a larger scale.

sun would lie in the direction B C (Fig. 13) and Mars in the direction B A.

Six months later (March 23rd, 1910) the earth would be at D, and on that date (according to "Whitaker") Mars

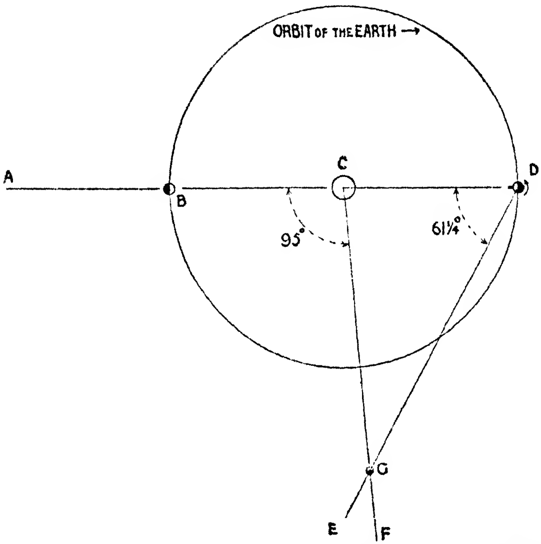


FIG. 13. DIAGRAM FOR CALCULATING THE DISTANCE OF MARS

Distance from:—

Line G D = Earth to Mars.
,, D C = Earth to sun.
,, C G = Mars to sun.

crossed the meridian at about 4.12 p.m. and the sun about 12.7. Therefore the sun was about 4 hours 5 minutes in advance of Mars. Reckoning 15° per hour as before, we find that the direction of Mars was

then inclined at $61\frac{1}{4}°$ to that of the sun—therefore he lay somewhere along the line D E. Now let us imagine ourselves situated at the centre of the sun. Mars travels once round the sun in 687 days; while from September 23rd to March 23rd is only 182 days; but if Mars moves through 360° in 687 days he will move through about 95° in 182 days; that is simple proportion. Therefore, from the centre of the sun, we should see Mars in the direction C F.

Now we can easily see that if Mars is along the line C F and also along D E he must be at G, where the two lines cross. Therefore the sides of the triangle C D G represent to scale the distances of the three bodies. If we measure them we shall find that the proportion of C D to C G is as 24 is to 37. Therefore we say—

24 : 37 : : 93 (million miles) : 143 (million miles) (about).

The astronomers' mean distance is 141,500,000, so that this time we are nearer still.

It was by methods such as these that Kepler found the distances of the planets from the sun, and by calculating their distances when at different parts of their orbits he was able to find the exact shape of the latter.

Our calculations, however, have shown us merely the comparative or relative distances of the bodies; it was only because we knew the distance of the earth from the sun that we were able to calculate the actual distance in miles of the other two planets. How, then, is that 93,000,000 miles measured?

Measuring the Universe

Measuring the Distance of the Sun.

It has been done by several methods, but I will describe the latest that has been invented. So new is this that the most favourable opportunity of trying it has not occurred and will not do so until 1924. In that year the tiny planet Eros will come within 15,000,000 miles of the earth, quite close as planets go, and there is little doubt that he will then reveal all the distances of the different bodies in the solar system more accurately than they have ever been known before.

The Use of the little Planet Eros.

The reason why Eros will be so valuable for this purpose is because he comes very near, and he is such a fine sharp point of light that his positions can be accurately determined, just as we can measure more accurately with a rule marked with fine lines than we can with one marked with coarse lines.

The Heliometer.

The instrument used will probably be that called a Heliometer, since it was first invented for the purpose of measuring the diameter of the sun, the Greek name for which was Helios. It will be described in a later chapter, so that it will be enough to say here that it is capable of measuring the angular distance between two bodies very accurately. Early one evening the angular distance of the small planet from one of the stars will be measured, and several hours later it will be measured again. That is all.

The Triangle once more.

It seems remarkably simple, and at first sight it does not appear to have the remotest bearing upon the distance of the sun. Let us see, then, how it works out. In Fig. 14 the curve represents a part of the earth's

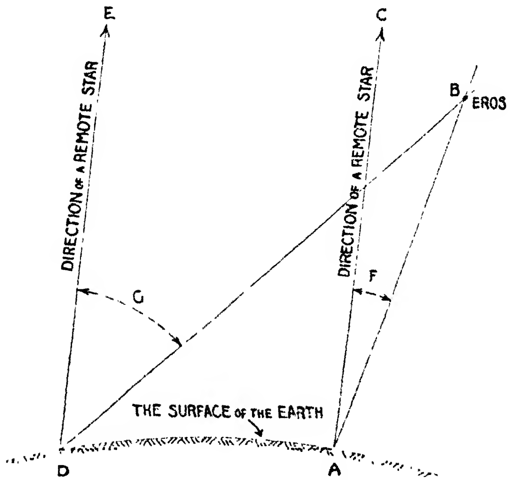


Fig. 14. The Latest Method for Finding the Distance of the Sun

circumference, with the observatory at A. Eros is first seen in the direction A B and the star in the direction A C, the heliometer recording the size of the angle F.

By the time that the second observation is made, the rotation of the earth has carried the observatory to D, and from there the planet is seen in the direction D B

and the star in the direction D E, the heliometer showing the angle G.

Now it is true that the lines A C and D E are both directed to the same star and so must be inclined to each other, but that star is so far off and the inclination is consequently so slight that they are for practical purposes parallel. The two angles measured by the heliometer, therefore, enable us to reckon the size of the angles at the base of the triangle B A D, and the length of the base itself can be easily calculated from the size of the earth, and the time which elapsed between the two observations. Thus we have all the information necessary to find out all about the triangle, including the distance IN MILES of the planet at its apex.

Now in the diagram (Fig 13) the lines G D and D C show the proportion between the distance of the earth from Mars and the distance of the earth from the sun; by the same methods we can find out the proportion which Eros' distance from us bears to our distance from the sun, and that proportion then enables us to convert the distance of Eros in miles into the distance of the sun in miles.

Measuring the Earth.

But even yet we have not got to the "yard measure" referred to in the heading of the chapter; we shall now see where it comes in.

The base of the triangle just referred to—the distance, that is, between the two positions of the observatory—

is known because we know the size of the earth: That is known from actual measures taken on the earth's surface; for instance, the distance from Shanklin in the Isle of Wight to a place in the Shetlands has been measured with extreme accuracy for this very purpose of finding out the size of the earth.

Such a measure is made with a portable telescope called a Theodolite by the method called Triangulation; a base line is measured and then a beacon set up, perhaps ten miles away; the direction of the beacon from the ends of the base line is observed with the theodolite, and so the size of the imaginary triangle of which the base line forms one side and the beacon the apex is calculated. Then one of the *calculated* sides of the triangle is used as the base of a fresh triangle, and so the process is carried on until a network of imaginary triangles stretches for hundreds of miles.

Now the whole of this system of triangulation depends upon the base line, which is actually measured, not with a tape measure, for that would not be accurate enough, but with special rods so constructed that they do not vary with the temperature.

The Imperial Standard Yard.

And that brings us to the yard measure. In the basement of an old house at Westminster, facing the Houses of Parliament and close by the Abbey, there is kept with the utmost care a metal rod which is exactly a yard long; or, rather, it is the other way round—the

yard is exactly as long as that rod. It is the Imperial Standard yard.[1]

With it the rods used in measuring the base line were compared and tested, so that we have the following chain of measures:—

The Imperial Standard yard.
The special measuring rods.
The "base line" (at a place called Misterton Carr, Notts).
The distance from Shanklin to Balta (in Shetland).
The size of the earth.
The distance of Eros from the earth.
The distance of the earth from the sun.

Each of these forms the basis from which we are able to arrive at the next one. Thus we pass from the yard measure to the size of the solar system. Finally we go one step farther, and from the distance of the earth from the sun we can ascertain the distance of some of the stars.

Measuring the Distance of a Star.

The method is similar to that used to find out the distance of Eros, only the stars are so far off that the movement of an observatory, due to the rotation of the earth, makes no appreciable difference in their

[1] At the office where this standard yard is kept they have a machine called a Comparator, for comparing other yard measures with it.

This machine can detect a difference of *one forty-thousandth* of an inch.

positions. If, however, observations are made six months apart, that is, from opposite sides of the earth's orbit, a distance of about 186,000,000 miles, some of the nearest stars reveal themselves by a very slight apparent movement in relation to the more remote ones, and from that their distances can be calculated.

The measurement of this apparent movement of a star is a most wonderful triumph both for the astronomer and the optician, for the angular measure of it in the case of the nearest star is *less than* two seconds (or the one thousand eight hundredth part of a degree), which is about equal to the diameter of a penny seen two miles off, and much smaller angles even than that are measured accurately in the case of more distant stars.

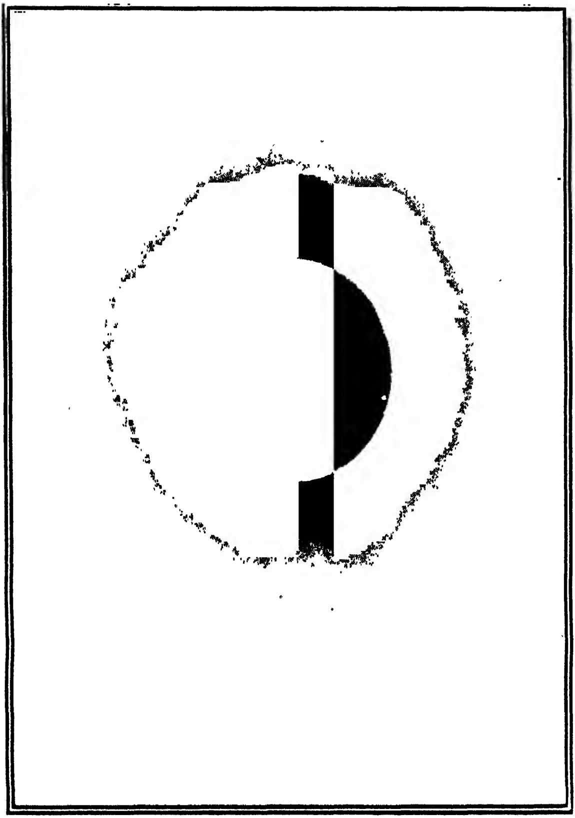
Measuring by Photography.

Another means used for the same purpose is photography.

A series of photographs of a group of stars are taken at intervals and then minutely examined and compared, when a slight movement of any of the stars can be detected and measured.

The Distance of the Moon.

The distance of the moon was ascertained in a different way, although the same in principle. It was observed at the same moment from two observatories, and the direction in which it was seen from each gave the inclination of two sides of the triangle, while



J. P. Kett[illegible], F.R.S.

THE ECLIPSED SUN

Taken by an amateur, with an ordinary camera, at Burgos, Spain, in August, 1905.

To face page [illegible]

the distance between the observatories gave the length of the base.

Thus we have seen how, by a series of operations, the yard measure has been used to measure the distance of even remote "fixed" stars.

CHAPTER VII

PHOTOGRAPHING THE MOON

THE most interesting object in the sky, to the amateur, is the moon. For one thing it is our own property, as it were; then it is the nearest to us of all the heavenly bodies, so near, in fact, that although small it appears to be the same size as the sun; then its movements are so rapid that we can almost see it travelling among the stars; it is never the same two days together; it changes in appearance too, and even in a small telescope we can see many of the details on its surface.

A Series of Pictures.

As a subject for photography it is unrivalled, and quite simple appliances are able to produce surprising results. I have a quarter-plate camera with rectilinear lens; such a lens is composed of two separate lenses screwed one in each end of a brass tube; by taking out the back one and using the front only the image is about doubled in size and I can get a beautiful little picture about one-eighth of an inch in diameter, which if examined through a pocket magnifier shows a wonderful amount of detail. A moderately fast plate

should be used, and a very short exposure given with a small stop. It is well to err on the side of *under*-exposure, if anything.

By leaving the camera in the same position, and exposing the plate at intervals of, say, five minutes, a series of these little pictures can be got on the same plate; this is a specially good way of observing an eclipse, as the progress of the earth's shadow can be clearly seen.

Tracing its Movement.

For photographs of the moon's position I use the complete lens and a very rapid plate. That is because the size of the moon in the picture does not matter, nor does it matter if the moon be over-exposed; on the other hand, we want to record the stars clearly, so the brighter image which the complete lens gives and the more rapid plate are necessary.

If we expose for about half an hour to an hour we can detect the fact that the moon is not moving as fast as the stars; or, to look at it in another way, it is moving among them in the opposite way to the daily movement of all, just as the sun does, only faster.

This change of position is made plainer still by two photographs taken on consecutive evenings.

The Moon's Wanderings.

Now how can this movement be explained?

Let us just see where the moon is to be found in the sky at different times. One night, for instance, soon

after the sun has set, we shall find it in the act of setting too. A night after it will do the same, only the time between sunset and "moonset" will be longer. This interval will increase daily, until after twelve days or so the moon will rise as the sun sets, and we shall find it to the south at midnight, just as the sun is to the south at noon.

The rising of the moon continues to get later and later, until we shall find it (only we shall have to get up early to see this) rising just a short time before the sun. Then comes a day when we don't see the moon at all, after which it goes through the whole series over again.

We shall find, too, that it takes 29½ days to go through the complete circle. Consequently it moves through about 13 degrees in a day.

Now the sun is due south at noon, and he takes twenty-four hours to travel right round the earth and come back to noon again. Therefore at midnight he will be due north, or just half-way round. In other words he will be round the other side of the earth, exactly opposite where he was at noon. From what we know of his motion we are sure that this is the case.

We know already that if we see a planet to the south at midnight it is on one side of the earth and the sun on the opposite side, and it is just the same with the moon. When, however, we see the sun and moon near together we know that the moon must be on the same side of us as the sun, and all three bodies nearly in a line. We have seen, too, that the moon sometimes rises before the sun and sometimes after, so that sometimes it is one

side of the sun, as we look at them, and sometimes the other. What simpler explanation, now, could we have of these movements than that the moon is revolving round the earth once in 29½ days?

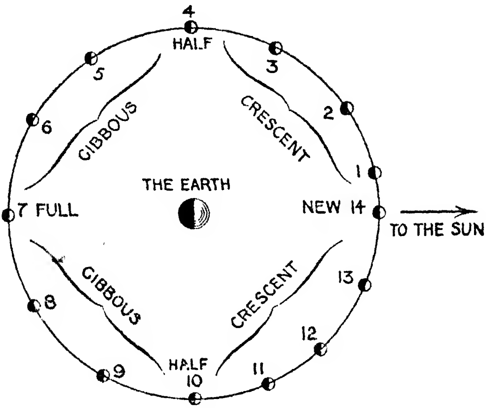


FIG. 15. THE "AGE" OF THE MOON

When the moon is at 14 it is "New" and invisible.
At 7 it is "Full."
At 4 and 10 it is a "Half-moon."
As it passes from 14 to 7 it gradually waxes or grows.
As it passes from 7 to 14 it wanes or diminishes.

The Moon's Monthly Journey.

A glance at the diagram (Fig. 15) will help us to see this. When the moon is at 1 it will seem to us to be a little to the left hand of the sun; when at 2 it will appear still more to the left, and so it will set later. At 3 it will be farther to the left still, and will set later still, and so on until we get to 7, when we see it will be

exactly opposite the sun, and then it will be to the south at midnight. After that, as it passes through 8, 9, and 10, it will appear on the right of the sun and gradually getting nearer to him, until at 13 it seems quite close. At 14 the sun and moon will lie in the same direction, and then we shall not see the moon at all, for it will rise and set at the same time as the sun.

The Moon's Phases.

We have therefore seen with our own eyes things which lead us to believe that the moon is going round the earth. We cannot be quite sure, however, unless we can find other things which will confirm this. Now changes in position are not the only things which we can notice. We see changes in appearance too. One day we do not see the moon at all (we then say it is "new"). During the next few days it looks like a thin curve of light which we call a "crescent." At the end of about seven days it looks like a moon cut in half, so we call it the "half-moon." Then the flat side swells out, during which time it is called "gibbous," until, at the end of about fifteen days, it is a full round circle, and so we speak of it then as "full" moon. After that it begins to dwindle away and goes through the same series once again, but in the reverse order, until it is "new" once more. Those changes are called the "phases" of the moon.

A Simple Experiment.

Now let us see if these phases will confirm our idea that the moon revolves round the earth. Stand in front

of a lamp, holding a ball out at arm's-length in front of you, and turn slowly round on your heel watching the light and shade on the ball as you move. You will then represent the earth, the ball will be the moon, and the lamp the sun, and you will see all the phases of the moon reproduced on that ball. That will confirm our idea that the moon revolves round the earth just as that ball revolves round you, and it also shows that the moon is not in itself a bright body, but that it reflects the light of the sun just as the ball reflected the light of the lamp. It also fits in with the fact that we cannot see the "new" moon, since it will, at that phase, have its dark side turned towards us.

Thus we may now feel fairly certain that the moon goes round the earth and also that moonlight is really reflected sunlight, and both these beliefs will be confirmed further when we come to talk about eclipses.

The Moon's Distance.

The moon is 230,000 miles from the earth. By carefully measuring the apparent diameter of the moon at different times it is found that its orbit, like that of the earth, is not a circle but an ellipse, and so its distance varies, but the figure I have just named is the average or "mean" distance.

The Moon's Diameter.

The moon's diameter we can find out for ourselves. If we photograph it and the sun with the same lens we shall find that they appear to be the same size, and as

we know that the apparent size of any object varies in accordance with its nearness to us we can say that the moon is as much smaller in diameter than the sun as it is nearer than the sun.

So, by simple proportion, we can state our sum thus: As the distance of the sun is to the distance of the moon, so is the diameter of the sun to that of the moon. The answer is 2160 miles.

We always see One Side.

If we watch the moon carefully, or photograph it on a number of different nights, we see that there are certain marks on it, and we shall get to know the marks well enough to recognise them. Then we shall discover that they never move. What does that mean? At first one is inclined to think it means that the moon does not rotate upon an axis, yet that is wrong, for it shows that it does rotate but that the period of rotation is exactly the same as the period of its revolution round the earth. Take hold of a post with one hand and, without letting go, walk round it once. You will find that in walking round you will face all the points of the compass in succession and so you must have turned round once upon an axis, yet the post, if it had eyes, would have seen the same side of you all the time.

There have been several explanations of this, but the one most generally accepted is that the moon used to rotate, but that ages ago, when it was in a hot plastic state, the earth's attraction caused very powerful tides

upon the moon. The moon does the same for us now; it pulls some of the water into a heap and as the earth spins round it holds this heap of water and makes it rub against the surface of the earth just like the brake-blocks rub against the wheels of a locomotive. Thus it is tending even now, in all probability, to slow down the rotation of the earth and in time will actually lengthen our day perceptibly.

In precisely the same way the earth caused a heap of gaseous or liquid matter to be formed on the moon, and the friction of this heap against the body of the moon has made it gradually go more and more slowly.

It is believed that even the solid earth is pulled out of shape by the attraction of the sun and moon, and all the planets, too, are similarly affected by the sun, so that ultimately all the planets will probably keep one face turned to the sun, as the moon does to us, and as, it is thought, Mercury and Venus do already.

The Moon has no Air.

The moon is, of course, by far the nearest body to the earth, and so we can see more of its details than we can of those of any other heavenly body. There is another reason, too, why we get a very clear view of the moon, and that is that it has no atmosphere and no clouds. Even in a small telescope or field-glass we can see a great deal that is very interesting. At about "half-moon," or a little before, when the sunlight is shining on a little less than one-half, we can see bright specks on the dark half just near where the bright half leaves

off. Those specks are the sunlight reflected off the tops of the great mountains the lower slopes of which are in shadow. The surface of the moon is a dry arid plain broken up by huge ring-like mountains or craters, like the blisters on a painted surface after it has been subjected to heat. These huge craters are some of them 50 or 60 miles across and 20,000 feet high.

The Moon's Craters.

The size of the craters is easily found by comparing them with the size of the moon itself, which, of course, we know, and the height is obtained by measuring the lengths of the shadows which they throw when the sun is shining obliquely upon them.

Occultations.

There is a very interesting observation which seems to show that the moon has no atmosphere. It frequently happens that it passes in front of a star and then the star is said to be occulted by the moon. In any good almanack such as "Whitaker" there will be found a list for each month giving the names of the stars and the days and the exact times when occultations will take place.

Now when the sun goes down below the horizon a curious thing happens. The upper layers of the air which surrounds the earth reflect some of the rays of light which come from the sun down into our eyes in such a way that we continue to see its light for a while after the sun itself has disappeared; in the same way, at

sunrise, we see a glow in the eastern part of the sky before we actually see the sun itself.

In precisely the same way we should, if the moon had an atmosphere, see the light of the occulted star for a little while after it had itself gone behind the moon, and we should see a faint glimmer, too, a little while before the star really emerged on the other side, but as a matter of fact it disappears and reappears with startling suddenness, so that we have there an evidence of the absence of air in the moon.

Too Small to have an Atmosphere.

It is believed, too, that the moon is too small to keep an atmosphere, even supposing it ever to have had one. If a gun could be made that would send a shot at a speed of seven miles a second, and it were fired vertically, the shot would never come down again; the momentum would be so great that the attraction of the earth would not be sufficient to pull the shot back. Now air is believed to consist of tiny particles called molecules in very rapid motion, and if they moved fast enough they too would shoot off into space just as a seven-mile-a-second cannon ball would do, but fortunately for us they do not move sufficiently rapidly. Since, however, the moon is so much smaller than the earth, its attractive power is much less, and consequently in *its* case the molecules would fly off never to return.

No Water.

That there is no water there is shown by the fact that the moon can always be seen quite clearly whenever

our atmosphere is clear. If there were water there the sun would be sure to turn some of it into vapour, and so we should sometimes detect clouds on the moon's surface.

Since it has no air it must be very cold. The air by which we are surrounded acts like a trap for the sun's heat. The rays from the sun can penetrate easily through it, but the rays of heat as radiated back by the earth cannot. Thus the heat can get to us from the sun, but it cannot get away again. The moon, however, having no such blanket around it, loses the heat as fast as it receives it from the sun. It must, therefore, be extremely hot during the day while the sun is actually shining, but intensely cold at night, and as the night is as long as fourteen of our days it is evident how cold it will get during that time.

We may therefore think of the moon as a huge mass of rock, without air, water, or the possibility of life of any kind. A more dreary, desolate place it would be impossible to imagine.

The Moon's Heat.

The moon reflects a little of the sun's heat on to us, but very little. It has been calculated that we get more heat from the sun in half a minute than we do from the moon in a year.

Earthshine.

There is one thing which we can notice about the moon sometimes which is very interesting to us. When

at its "crescent" stage we may see, in addition to the bright strip illuminated by the sun, the whole of the rest of the surface faintly illuminated. That is the *reflection of our own light*, and it shows how brilliantly our earth must be shining.

If we could get to the moon we should see a magnificent spectacle. The earth would sometimes appear like our "full moon," but it would be four times the diameter, and probably brighter as well. To the inhabitants of Venus or Mars, too (if there are any), our earth must be the brightest star in the sky.

The Two Kinds of Month.

We have seen that if we take the sun as our fixed point by which to reckon the movements of the moon, it completes a revolution in $29\frac{1}{2}$ days. We also know, however, that the sun itself is apparently moving, so that the real time which the moon takes to revolve round us must be obtained by comparing it with the stars. In other words, we can measure the revolution of the moon in the same two ways that we do the rotation of the earth, and just as we have a solar and a sidereal day, so we have a synodic month (as that reckoned by the sun is called) and a sidereal month. The latter is $27\frac{1}{3}$ days. Neither of these fits in with the "calendar month," which is quite artificial.

ECLIPSES

Every now and then an event happens which we call an eclipse, and when that occurs the celestial photog-

rapher has a fine chance. It may occur to the sun or to the moon, and as far as appearances go it is the same thing in each case—the light of the heavenly body is obscured, more or less, for a time. If the whole face of the body is affected the eclipse is called "total," but if only a small part is darkened, then it is called "partial."

Eclipses of the Sun.

We have just seen that every time the moon is "new" it is in a straight line between us and the sun. It would seem from that as if it would shut off the sun's light from us and so cause an eclipse every month, and so it would do but for one thing. The path of the moon is very nearly on the same plane as that of the earth, *but not quite.* The result is that generally the "new" moon is either just above or just below the sun as seen from the earth. Occasionally, however, it does come in between us and the sun, and then we see what is called a "solar" eclipse or eclipse of the sun.

There must be at least two of these eclipses every year, and there may be as many as five. Astronomers can predict them with the utmost accuracy, telling us to the minute when the first sign of the eclipse will occur. This seems at first sight impossible, but it is not really so very difficult.

We know that the sun, moon, and earth are in line every new moon, and it only remains to ascertain whether the moon will then be in that part of its path which is on a level with the path of the earth.

A partial eclipse of the sun has been seen by most of us, and while it is interesting it is not very impressive. The sun looks as if a piece had been bitten out of it; that is all. In China this fact has led to the beating of drums and the making of hideous noises during an eclipse, the idea being to frighten away the dragon which the Chinese suppose is eating up the sun.

A total eclipse, on the other hand, is a most impressive sight, and of great scientific importance, for then the Chromosphere, Solar Prominences, and Corona can be seen as at no other time.

Eclipses of the Moon.

When the moon is full, you will remember, it is exactly in line with the sun, but on the opposite side to the earth. At "new" the order of the bodies is sun, moon, earth, and at "full" it is sun, earth, moon. So, in the same way, if full moon occurs just as the moon is passing along that part of its orbit which is level with the ecliptic, the earth will intercept the light from the sun to the moon, and so instead of acting like a huge mirror hung in the sky, throwing down upon us the light of the sun, the moon will appear quite dull, often not illuminated at all. Indeed, it would always be invisible at such a time were it not for the fact that a little of the sun's light passing through the earth's atmosphere is sometimes refracted out of its straight course and so falls upon the moon. Fig. 16 will help to explain this.

A Working Model.

Both kinds of eclipse can be well illustrated by holding a ball in the hand at arm's-length and standing in front of a lamp. At first hold it up so that it hides the lamp—there you see the "solar" eclipse. Then

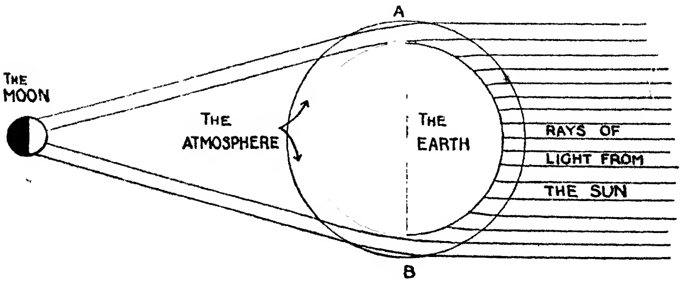
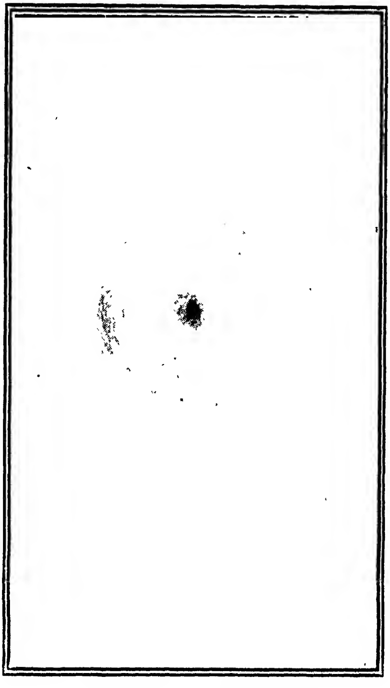


FIG. 16. WHY THE ECLIPSED MOON IS NOT ALWAYS DARK

If there are clouds in the atmosphere at A and B, then the light may be *entirely* cut off from the moon.

turn your back on the lamp so that your shadow falls on the ball and you have an illustration of the "lunar" eclipse, or eclipse of the moon.

There may be as many as three eclipses of the moon in a year, but there can be only seven eclipses altogether of the sun and moon.



SKETCH OF HALLEY'S COMET

As seen with the naked eye in London on Sunday, May 22, 1910. This sketch was made *as a negative* with lead pencil on ground glass, and a print taken off it just as if it were an ordinary photograph negative. This is a very easy way of drawing celestial objects.

To face page 96

CHAPTER VIII

A WORKING MODEL OF THE SOLAR SYSTEM

IF you look at the great planet Jupiter through a small telescope or a pair of good field-glasses you will see, quite close to him, three or four tiny stars. If you look again the next night or even later in the same night you will perhaps find that there is one more or one less, and at any rate they will have altered their positions somewhat.

These little objects are moons or satellites revolving round the planet and so forming a perfect model of the sun and planets. These help us to understand the solar system, for we can view it from outside, whereas, our earth being itself a member of the solar system, we cannot so easily see all that is going on in it. If we needed any further proof that the earth and the planets go round the sun we should be quite right in saying, "Here is a system in which there are smaller bodies revolving round a larger one, therefore it seems only probable that our earth and the other planets may be doing the same." That would be what is called reasoning by analogy.

The Sizes of the Moons.

Two of these moons are about the same size as our moon, while two are a little larger. The nearest is about

a quarter of a million miles from the planet and the farthest about a million. There are four others, making eight in all, but they are too small to be seen except through a large telescope.

Occultations and Eclipses.

With a telescope we can see these moons at times pass behind the back of Jupiter. That is called an occultation, the same word that we used to describe the disappearance of a star behind the moon. At other times they suddenly disappear before they quite reach the planet. What can be the cause of that? We have there another proof that the planets are not self-luminous, that is, they have no light of their own but simply reflect that of the sun; that sudden disappearance is the passing of the satellite into the shadow behind Jupiter. If either the planet or the satellite were shining with its own light we should still see it.

Transits.

The same thing is illustrated at other times when we can see a tiny black spot passing across the disc of Jupiter—that is the shadow of the satellite as it passes between the planet and the sun. At other times we may see the moon pass across the face of the planet, or at least we may see it approach one side and emerge the other. We cannot see it actually passing across, as they are both bright. This is called a "transit" and is just what happens very rarely when Mercury or Venus passes across the sun's disc. In the latter case, however,

we see the planet as a black spot against the bright background of the sun. That is because the light in both cases comes from the sun; when we see a transit of Venus or Mercury the planet has its dark side turned towards us, whereas in the case of a transit of one of Jupiter's satellites the bright side is turned towards us.

So we can see transits, occultations, and eclipses taking place in rapid succession, giving us frequent glimpses of things which in our own system only occur at rare intervals.

The moons revolve round Jupiter in 2, 3½, 7, and 16½ days respectively.

How the Speed of Light was Discovered.

Now we are told that light travels at the rate of 186,000 miles per second. How was that found out? It was Jupiter's moons that told us. When they were discovered the planet was very near the earth, near what is known as "opposition," which means that the planet was on the opposite side of the earth to the sun. A little thought will show that when that is the case the two planets are about as near together as it is possible for them to be (see Fig. 17). Well, the movements of the moons were carefully watched and measured, and time-tables were made out showing the exact times when the occultations, etc., were to take place.

An Astronomical Puzzle.

Now, as the earth passed on its way, it gained upon its fellow planet, until Jupiter was in "conjunction," that is to say, was on the same side of the earth as the sun, which means that the two planets were about as far apart as it was possible to be. As Jupiter got farther away the time of the occultations got later and later until they were, at the time of conjunction, about 1000 seconds behind the time-table. Then they began to

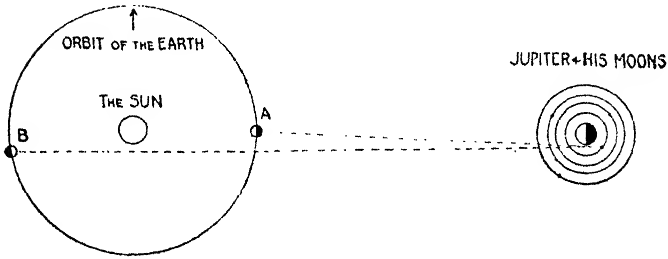


FIG. 17. THE SOLUTION OF THE "JUPITER PUZZLE"

If the Earth be at A it is about 186,000,000 miles nearer to Jupiter than if it were at B.

get earlier again, so that by the time opposition came round again the time-table appeared to be correct. It could not be, therefore, that the time-table was wrong, but it must evidently have something to do with the distance apart of the two planets. Soon the true explanation was hit upon. It must be the time which light takes to pass across the earth's orbit.

Measuring the Speed of Light.

But how do we know that that was the true explanation? We can find out in this way. Suppose we set up an apparatus like a magic-lantern with which we can send a powerful beam of light to a distance, and suppose that we direct it on to a mirror a mile away. The light will then be reflected back to us, and when it reaches us it will have travelled two miles. If we can place a shutter in front of the lantern and measure the time between the opening of the shutter and the moment

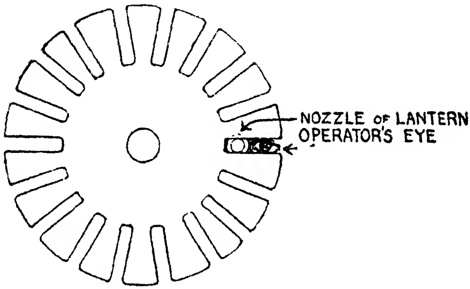


FIG. 18. SLOTTED DISC FOR MEASURING THE VELOCITY OF LIGHT

If this be rotated very fast, light which leaves the lantern and passes through one slot, may be reflected back by a distant mirror and reach the eye through the *next* slot. The time which the disc takes to rotate the distance between two slots will be the time which light takes to travel to the reflector and back.

when the light reaches us back from the mirror, that will tell us the speed of light. Of course the interval is so short that it is not an easy thing to measure, but a very simple way has been found of doing it.

A large tooth-wheel or disc like Fig. 18 is placed in

front of the lantern and is made to revolve. As the slot between two teeth passes in front of the lantern it allows the light to pass out, but a moment later the light is cut off by the next tooth. The teeth are made very deep so that the experimenter can also look through the same slot that the light is passing through, and while the wheel is turning slowly the light passes out through a slot and back to the eye before the next tooth has had time to intercept it. If the speed be increased gradually, however, there will come a time when the light which leaves as one slot passes the lantern will arrive back just when the following tooth is in front of the experimenter's eye, and if it be increased still more the point will be reached when the light leaving through one slot will pass back into the eye through the next slot. The time, then, which the wheel takes to turn from one slot to the next is the time light takes to travel two miles. This experiment shows that light travels about 186,000 miles per second, and so confirms the explanation as to the apparent variations in the movements of Jupiter's moons. It also confirms the accuracy of our calculation of the size of the earth's orbit.

CHAPTER IX

HOW NEPTUNE WAS DISCOVERED

MOST of the heavenly bodies have been discovered through people seeing them. The older planets, from their brightness, forced themselves upon men's attention, while Uranus and the earlier planetoids were noticed by a happy accident. More recently photography has discovered many small planets and some satellites, among which is the remarkable case of the eighth satellite of Jupiter, found some years ago on a photograph by Mr. Melotte, of Greenwich Observatory, and repeatedly photographed since, but which has never been seen yet by the eye.

A Planet discovered on Paper.

The most remarkable of all, however, was the discovery of a planet "on paper" simply by calculations, and the interest of it was increased further by the fact that two men, each quite ignorant of what the other was doing, made the discovery simultaneously.

The Discovery of Uranus.

In the year 1781 Sir William Herschel was examining some small stars when an object attracted his attention which he had not noticed before. At first he thought it

was a comet, but eventually it turned out to be a planet whose orbit lay outside that of Saturn, the outermost of the planets known up till then. To it the name of Uranus was given.

The new planet was, of course, carefully watched, its motion was measured, and its future movements were predicted. As time went on, however, these predictions

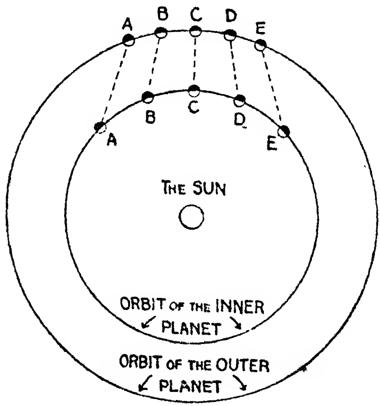


FIG. 19. HOW TWO PLANETS INFLUENCE ONE ANOTHER

turned out to be slightly wrong, and the only way by which the difference could be accounted for was by assuming that there was another planet further away still which yet remained to be discovered.

How the Planets interfere with each-other.

This will be more easily understood if we look at an instance of the way in which planets act upon each

other. Suppose the two circles in Fig. 19 represent the orbits of two planets. The inner one will, according to Kepler's Law, be travelling considerably faster than the outer one, so that periodically it will pass it. As the faster one approaches the other, passes it, and then recedes from it, their mutual attraction will have a considerable effect upon the speed of both, but for simplicity's sake we will confine our attention to the effect produced upon the inner by the outer one.

When they are both at A, the outer will pull the inner along, thereby increasing its speed. At B the same will still be happening, but after passing C the effect will be the opposite, for at D and E it is clear that the inner planet is being pulled back or restrained in its career by the attraction of its fellow. All the planets affect each other in this way.

Looking for the Unknown Planet.

So in 1843 an English mathematician named Adams set to work to investigate the matter, and after years of labour he succeeded in calculating that a planet of a certain size, at a certain distance from the sun, and in a certain position in relation to Uranus, would have the effect of producing all those variations which had been noticed in Uranus' movements. He predicted, moreover, that on a certain date the planet, if it existed, would be visible in a certain place in the sky. Unfortunately, however, there was some delay in verifying this prediction, and a Frenchman named Le Verrier was thus able to forestall Adams.

Le Verrier had been engaged upon the same problem at the same time, and although Adams' calculations were completed first, the Frenchman had the good fortune to send his information to an astronomer friend at Berlin Observatory, where, it so happened, they had just completed a survey of that very part of the sky where the new planet was said to be. This friend looked at the sky the same evening that he received the information, September 23rd, 1846, and there was the planet in almost exactly the position that Le Verrier had indicated.

At Cambridge University, however, where Adams' calculations were tested by observation, the particular part of the sky concerned did not happen to be so well known, so all the stars in that region had to be carefully observed for some time to see whether, among the vast number of tiny stars there, there was one which exhibited the properties of a planet. As a matter of fact it was seen on August 4th, but was not recognised as a planet till later.

Thus Adams completed his calculations first, but Le Verrier was the first to get his success verified by actual observation, and so the names of these men have come to be linked together as the co-discoverers of the planet Neptune.

CHAPTER X

COMETS AND SHOOTING STARS

WE have records that even in very ancient times the world was sometimes startled and frightened by the apparition in the sky of a new body, often of large size, quite different in appearance from the familiar objects of the heavens. These were comets, and although they do not now fill us with dread, they arouse great interest when they are on view.

What a Comet consists of.

A comet usually consists of a bright centre, called the nucleus, with a less bright filmy part round it, and often, but not always, a train or tail of very great length. It is composed of very thin attenuated gas, so thin that compared with it our air is almost solid. Thus although a comet is often of enormous size it has very little mass or weight. In fact, it is estimated that an average comet is about one thousand times less in weight than an equal volume of our air would be.

No Danger in Comets.

The alarming articles which appear sometimes describing the dreadful things which "might happen"

through a collision between a comet and the earth, while they form very interesting reading to those who like having their flesh made to creep, have little basis in fact, for there can be little doubt that should the earth, in its majestic sweep round its orbit, ever encounter the flimsy structure of a comet, the air alone would have sufficient solidity to cleave its way through the obstruction as easily as a railway train can plunge through a cloud of smoke. Thus the material of the comet would never have a chance of approaching anywhere near the surface of the earth, and the earth's motion would suffer no appreciable change because of the impact.

The Earth has been close to a Comet.

There is reason to believe that the earth has passed through, or very near to, a comet without suffering any ill effects whatever, and the lightness of these bodies is shown very clearly by the fact that one of them has actually passed among the moons of Jupiter without disturbing them, small though they be. On the other hand, the attraction of Jupiter so pulled the comet out of its orbit that it went off in a new direction, and another one which ventured too near the giant planet was so upset in consequence that it has never been seen since.

The spectroscope shows that comets are, to a certain extent, at any rate, self-luminous, that is, they shine with light of their own, and not simply with reflected sunlight. Yet they are quite transparent, and fail to

dim the light of the faintest stars when they pass in front of them.

Comets' Orbits.

Mathematics show that if a body be given a start, and then continue to move under the combined influence of the original impetus and the attraction of the sun, it must travel along one of the four curves known as the Conic Sections. These are the Circle, Ellipse, Parabola, and Hyperbola, and which particular one the body will take depends upon the initial "push."

In the case of the planets the curve is an ellipse, and since that forms a closed figure they go round and round the same course over and over again. Some, at any rate, of the comets also move in elliptical orbits, and so turn up at regular intervals. There are about thirty of these "short-period" comets, so called because their periods of revolution round the sun are short. They return every few years, but are not noticed by the general public since they can only be seen through the telescope. The number of these small comets is frequently added to by "captures," the attraction of the great planet Jupiter being the means of drawing many stray comets into our solar system; some, on the other hand, are lost through their breaking up, and are never seen again, but the material of which they are formed is believed to go on revolving round the sun, as will be described presently.

Readers may have noticed that the predictions concerning comets are not so definite or so accurate as

those we are accustomed to get from astronomers; that is mainly because the vagueness of their shape and outline makes it difficult to measure their exact positions and movements.

For this reason there is some doubt about the orbits of the large comets which visit us occasionally and usually create somewhat of a sensation. It used to be thought that their orbits were parabolic (or in some cases hyperbolic) curves, which do not form a closed figure, and if that were so such a comet must be drawn from its course through space by the action of the sun, come racing towards him, and, after passing partly round him, dart off into space, never to come near our system again.

Now, however, it is considered possible that the orbits of all may really be ellipses, and that in the case of these rare visitors, the ellipse is so very elongated that the comet takes thousands of years, it may be, to complete its revolution. Thus, instead of being strangers to our system, paying us one visit and no more, they may be regular members of our solar family, whose last visit to the immediate neighbourhood of the sun is lost in antiquity.

Whatever the shape of the orbit may really be, it is only that part of it near the sun which comes within the range of our vision, and that particular piece is of almost the same shape whether it is an ellipse or a parabola. This fact and the indefinite shape constitute a formidable difficulty in deciding which kind of curve it really is.

In the year 1680 a comet appeared and the great

Sir Isaac Newton investigated its movements and calculated that it, like the planets, was controlled by the sun's gravitation and that it would return in about 600 years. This was the first time that the orbit of a comet was calculated in the light of Newton's famous "law of gravitation."

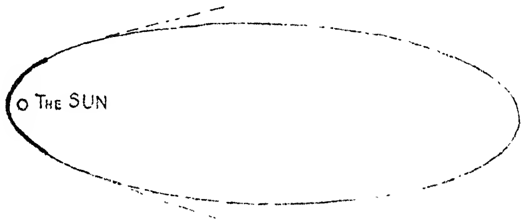


FIG. 20. THE ORBIT OF A COMET

A comet's orbit is at all events a very elongated ellipse, so that while at one time it is very near the sun, at other times it is very far distant. As its brightness is not very intense, however, we only see it in that part of its orbit which is comparatively near the sun, say the part shown by the thicker line; and as that part is indistinguishable from the corresponding part of a parabola (shown in dotted lines), it may be that some of them are moving in parabolic orbits.

Halley's Comet.

Two years later, in 1682, another comet appeared, and the great astronomer, Halley, carefully investigated it. He found its period of revolution and identified it as the same one which had appeared several times before. He also predicted that it would return about the year 1759.

This was the first time that such a prediction had been made capable of verification, and Halley himself

did not live to see it fulfilled, but in due course the comet arrived, thus placing beyond doubt the belief that it was revolving round the sun in a regular orbit just as the planets do. According to time-table it was due here again this year (1910), and although it was not the bright object which many people expected to see, it duly kept its appointment, as many of us can testify.

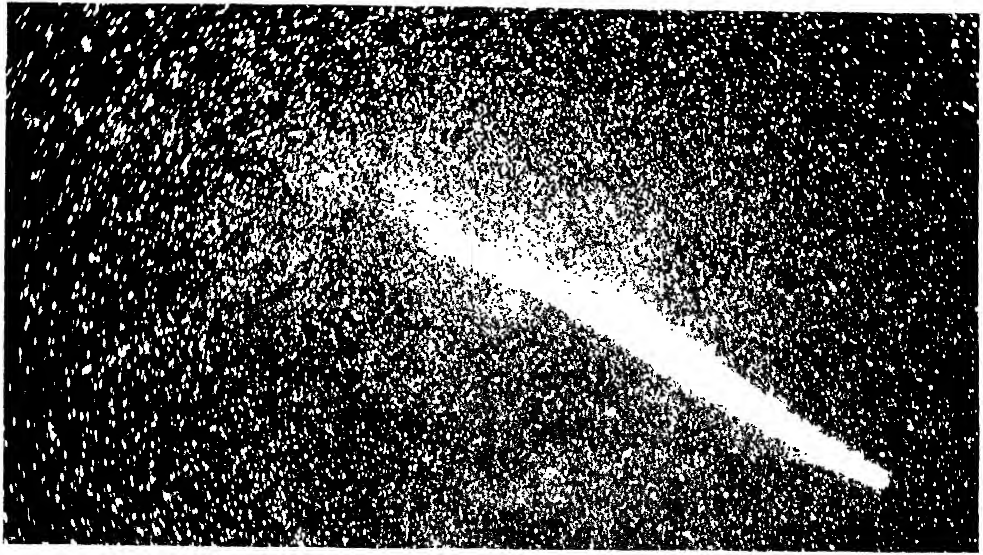
Its orbit is a very elongated ellipse, so that while at one time it is very near the sun it travels out beyond the orbit of Neptune, whose mean distance from the sun is the enormous one of 2,698,809,000 miles. No wonder it is invisible during the greater part of its journey!

SHOOTING STARS

We may often see, on a clear night, a bright object shoot across the sky, leaving a glowing trail behind it. It appears as if one of the stars had become detached from its place in the heavens and had fallen to the earth. Such are usually called shooting stars, or meteors.

How Comets break up.

A comet is rather like an overgrown, weak schoolboy, liable to be pulled about by his more robust comrades. It is always being strongly drawn by the sun, and all the planets are pulling at it too, with varying forces, according to their distance, and in different directions. Then, too, it has internal troubles of its own, for it is moving not in a straight line but round a curve, and



PHOTOGRAPH OF COMET "MOREHOUSE"

Taken at the Royal Observatory, Greenwich, on October [illegible] 1908, with a portrait lens of four inches aperture; exposure forty minutes. Length of tail shown about 10 degrees.

To face page 11[illegible]

whenever that happens some parts have to move faster than others. When a motor-car, for example, goes round a corner the outer wheels turn faster than the inner ones, and there has to be on every car a mechanism called the "differential gear," to permit of this difference in speed. There is no "differential gear" in a comet,

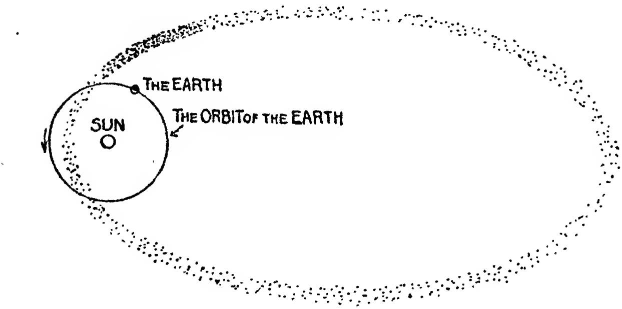


FIG. 21. A STREAM OF METEORS OR SHOOTING STARS

Here we see a stream of those tiny bodies which form shooting stars. They are all circulating round the sun in the same orbit as did the comet, of which they are fragments, and at certain times of the year the earth passes through them. When the densest part of the stream happens to get in the earth's way there is a specially brilliant display of celestial fireworks.

however; all the parts are trying, because of the momentum, to move at the same speed, yet, as I have just explained, they cannot do so and so they tend to become torn apart.

With these various forces acting upon them, then, and remembering how flimsy they are, it is not surprising to find that comets are apt to be rent in pieces. One comet, which used to be known as Biela's, at one of

its visits was found to have split up into two separate bodies; since then it has never been seen at all, and there seems to be little doubt that every comet must, in time, break up and the material of which it was composed become spread out along its orbit, each piece, of course, continuing to travel round the orbit, just as it did when it was a part of the comet. Moreover, the fragments then appear to condense into a solid form.

Streams of Broken Comet.

Thus there are revolving round the sun streams of these fragments, and sometimes the earth in its revolution passes through one of them, and thus intercepts many of the little bodies, which come racing towards us at terrific speeds until they encounter our atmosphere. Then the friction against the air makes them so hot that they shine for a moment like bright stars; only for a moment, however, for the heat soon converts them into vapour, and it is that hot vapour which forms the trail across the sky.

The Bombardment of the Earth.

There are millions of these falling upon the earth every day, although, of course, the casual observer only notices the very bright ones which fall upon a clear night. Many of them are but tiny objects, the size probably of small pebbles, and they are reduced to gas long before they reach the surface of the earth. Very occasionally, however, there comes one which is large enough to escape being entirely vaporised by the heat

and then it falls upon the earth with great force, burying itself in the ground to some considerable depth.

It is a good thing for us that we have the protection of our atmosphere, for without it these celestial bullets would be continually hitting us, in fact, we should need to live in bullet-proof houses and would only venture outside when absolutely necessary.

There are certain times in the year when shooting stars are specially plentiful; these times occur when the earth in its revolution passes through a stream. It is easy to see, too, that as a comet becomes broken up and its parts spread out along the orbit, there will generally be a cluster of these parts at the point where the comet originally was, and when the earth passes through such a cluster there is an exceptionally brilliant display of these celestial fireworks.

In Whitaker's Almanack will be found a list of the various "swarms" or streams of shooting stars or meteors as they are often called, with the dates and also the "radiant points," the particular part of the sky from which they appear to come. Some of the swarms are known by the name of the comet out of which they are formed, such as the Bielids—the remains of Biela's Comet—while others, such as the Perseids and Leonids, are called after the constellation in which the radiant point is situated.

It is possible that some of these little fragments may approach the earth in such direction and at such speed that instead of falling towards the earth they become satellites and go on revolving round our planet continually, tiny moons too small for us to see.

CHAPTER XI

THE ASTRONOMER'S INSTRUMENTS

THE TELESCOPE

OF the instruments used by astronomers, the chief, of course, is the telescope. Many wonderful discoveries were made, it is true, before it was invented—the observations of Tycho Brahé, for instance, were obtained without its aid—but many of the wonderful and interesting things which we now know about the heavens would never have been found out but for the telescope.

Refractors.

There are two kinds—refracting telescopes, in which the rays of light are refracted or bent by passing through a lens, and reflecting telescopes, in which the rays are reflected by a concave mirror.

Most people are familiar with an ordinary photographic camera. In it the light from a distant object falls upon a convex lens or combination of lenses, and in passing through it the rays are bent inwards, so that they eventually cross each other and form an inverted picture or image of the distant object upon a piece of ground glass. Now if we take a magnifying glass,

such as watchmakers use for instance, we can look at any part of that image through it, and in that way get a very much enlarged view.

Of course, the ground glass, being partially opaque, makes the picture very faint, but fortunately we can take the ground glass right away and still see the magnified image in the magnifying glass just the same, only much brighter.

There we have the principle of the refracting telescope. It is simply a large convex lens called the

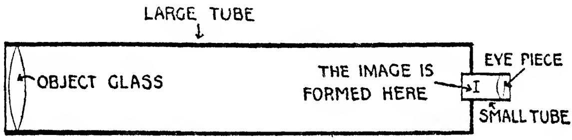


FIG. 22. DIAGRAM SHOWING THE CONSTRUCTION OF A REFRACTING TELESCOPE

"object-glass," which forms an image, which can be magnified and examined through what is really a microscope, called the "eye-piece." The object-glass and eye-piece are fixed at opposite ends of a tube (Fig. 22).

Reflecting Telescopes.

In a reflecting telescope there is a concave reflector at the bottom of a tube. The light enters the open end of the tube and is reflected back again, the rays being turned inward so as to form an "image," just as in the

case of a refractor, the image being then examined through a microscope in exactly the same way (Fig. 23).

The large telescopes at observatories are the product of the greatest possible care and skill, no expense being spared to make them as perfect as possible. The largest refractor in the world is about sixty feet long and has an object-glass forty inches in diameter; it is in the Yerkes Observatory at Chicago. The largest reflector, six feet in diameter. is to be found at Lord Rosse's private observatory at Parsonstown in Ireland.

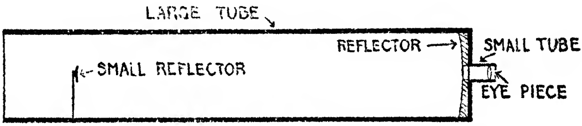


FIG. 23. DIAGRAM SHOWING THE CONSTRUCTION OF A "NEWTONIAN" REFLECTING TELESCOPE

There are several other types of reflecting telescopes, but they are all the same in principle.

Photographs taken through Telescopes.

Many observations are now made by photography. The eye-piece of the telescope is removed, a dry plate put in its place, and a photograph taken exactly as in ordinary photography. There are many advantages in this method. For one thing there is produced a permanent record which can be kept for future use; it contains fine details, too, which no drawing could give; and it can be examined, measured, and discussed, in a way that no ordinary visual observation can be. Then the greatest advantage of all is, that the sensitive plate

can perceive faint objects which the eye cannot see, for the eye is only sensitive to the light falling upon it at the moment, that which entered it the moment before having ceased to have any effect whatever. The plate on the other hand, while it might be unaffected appreciably by a very faint light falling upon it for a minute, would probably record that light if exposed to it for some hours.

A Photo of the Whole Sky.

There is now nearing completion a complete set of photographs covering the whole of the heavens, showing all the stars down to the fourteenth magnitude, probably about 30,000,000 stars. This was initiated by Sir David Gill when His Majesty's astronomer at the Cape, who photographed the comet of 1882, and then found that he had a splendid record of the adjacent stars as well. Other astronomers were also struck with this photograph, and finally an international conference was held, and observers of all nations, dividing up the heavens among them, set to work to produce a complete photographic chart of the whole sky.

THE SPECTROSCOPE

Another important adjunct to the telescope is the spectroscope. It used to be thought that astronomy was about played out, and there were few further discoveries within the range of possibility; but this instrument opened up new methods of investigation and has revealed many new wonders.

If a beam of ordinary white sunlight from a narrow slit in a shutter be allowed to pass through a prism, a three-cornered block of glass, it will not come out as it went in, a narrow strip of white light, but will be a broad band formed of "all the colours of the rainbow" in the following order—red, orange, yellow, green, blue, indigo, and violet. The explanation is that ordinary sunlight consists of all those colours mixed up together, and the prism has the power of sorting them

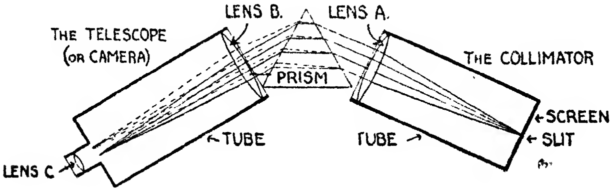


FIG. 24. DIAGRAM SHOWING THE CONSTRUCTION OF A SPECTROSCOPE

out and separating them. The band of colours, the "spectrum" as it is called, is viewed through a small telescope, or it can be photographed (Fig. 24).

Sir Isaac Newton again.

This method of breaking up the sunlight was discovered by Sir Isaac Newton, but it was not until later that its great utility was discovered. It was first noticed in the year 1802 that there were faint dark lines across the spectrum. Only a few were seen at first, but closer investigation and better instruments have revealed thou-

sands of them. At first they were a mystery, but after a time it was found that every glowing gas, when viewed through a spectroscope, produced a spectrum of its own consisting of certain isolated bright lines, and that these bright lines were exactly in the same position as some of the dark lines in the spectrum of the sun. On the other hand, the light from a burning solid, such as a candle, was found to give a perfect spectrum without any dark lines at all.

The next step was the discovery that if a light which gave a perfect spectrum was viewed through a glowing gas the result was not, as might have been expected, a combination of the perfect spectrum with the bright lines belonging to the gas added, but quite the opposite. The bright lines which the gas by itself would have produced were deducted from the other spectrum, leaving dark lines in their places. In other words, if we look through a cloud of glowing gas at a brighter light beyond, the spectrum will be that of the brighter light, but crossed by dark lines which will tell us the nature of the glowing gas.

How we can analyse the Sun.

When this was discovered it became evident that the bright light from the hottest part of the sun, that is, the central part, was shining through an outer layer of gas, glowing, it is true, but less brightly than the inner parts, and that the dark lines would give us a clue to the materials of which that gas and probably the whole sun were composed. The spectrum of each of the elemen-

tary substances of which the earth is built up was then carefully examined and compared with the lines in the solar spectrum, and a great many earthly substances were thus recognised as existing in the sun besides some which are not known here.

Analysing the Stars.

The stars can be subjected to this spectrum analysis in just the same way. For this purpose the spectroscope is fixed to the telescope, in place of the eye-piece.

The Fixed Stars are Suns.

The spectroscope shows all the stars to be suns, very like our own sun. It also reveals facts concerning them which are absolutely staggering when one first hears them stated. Many of those tiny points of light are not only suns but systems of suns, two, three, or four suns, perhaps, revolving round a common centre.

What the Spectroscope tells about the Stars.

It tells us, too, the speed at which they are revolving; by it we can even weigh them and find out their mass or the amount of stuff in them. Some, we know, are approaching us, while others are receding from us, and we can state how fast they move. We find too that there are dark stars which we cannot see, but which we can tell are there, nevertheless. And the whole apparatus consists of little more than a three-cornered piece of glass! How can it possibly reveal all that?

Light is conveyed by means of waves in that mysterious substance called the ether, which, it is believed, pervades all space. Sound is similarly conveyed by waves in the air, and most people have noticed that the sound of a locomotive whistle seems to change in tone as the engine recedes from the hearer. That is because each successive sound wave has a little farther to travel than its predecessor had, owing to the movement of the engine, and consequently the waves reach the ear a little farther apart than they would do if the engine were still; and so they produce a lower note. The exact opposite happens if the engine be approaching.

In just the same way, if a body whose light is being examined through a spectroscope be approaching or receding, a slight difference is caused in the rate at which the light waves reach us, and we see the effect in a slight alteration in the positions of the dark lines; if the body be approaching they are a little nearer the violet end of the spectrum than if it were still, while if it be receding they are nearer the red end. Moreover, their distance from their normal position indicates the speed of the body.

The usual method of finding this out is to photograph the spectrum of a star and at the same time the spectrum of glowing hydrogen side by side on the same plate. The lines in the hydrogen spectrum then form a standard from which the displacement of the lines in the star spectrum can be measured. Of course the variation in position of the lines is very small and the microscope has to be called in to assist in the examina-

tions of the photographs ; still, it is enough to show the direction in which some of the stars are moving.

Pairs of Stars.

About twenty years ago Professor Pickering, of Harvard College Observatory, invented a method by which he could photograph the spectra of a number of stars at once, and he then proceeded to take a large number of such photographs. Among the stars that were thus taken was Mizar, the middle one of the three which form the handle of the Plough, and on examination there appeared to be *two sets* of lines. Other photographs of Mizar showed only one set, while still others showed two sets at different distances apart. What could that mean?

It means without doubt that Mizar is really two stars, and consequently the spectrum is really two spectra one over the other. The two stars are revolving round a common centre, and so one will be approaching us as the other is receding, and the lines of one will be displaced towards the red and the lines of the other towards the violet, and so we shall see two sets. When they are both in line, as we look at them, they will be neither approaching nor receding, since their motions will then be sideways to us, and then there will be only one set of lines visible, for one set will be exactly on top of the other. Moreover, the distances apart of the lines will give the relative speeds of the two bodies, and the dates of the photographs will show the period of revolution, and from those facts the weight or mass of

the bodies can be reckoned. They must be at least forty times as big as our sun.

Two or more stars like this are called a "binary system." In this case it is a "spectroscopic binary,"

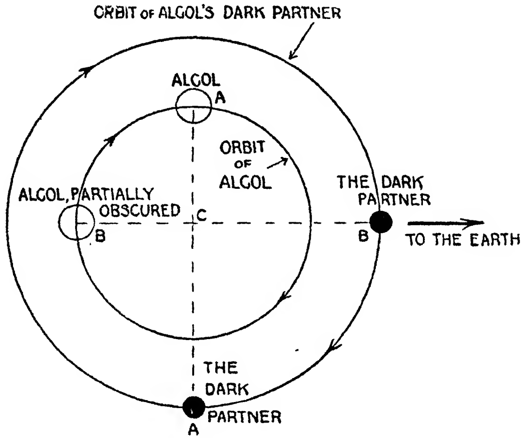


FIG. 25. THE "DEMON" STAR

Two stars, a bright one and a dark one, are revolving round the centre of gravity of the pair (C). When they are at A A the bright one is wholly visible from the earth. When they are at B B the bright one is partially obscured by the other.

but there are also "visual binaries" in which the two stars can be *seen* separately.

The "Demon" Star.

Then there is another star, Algol* by name, in the constellation Perseus, whose light varies in a very strange manner. Normally it is about second magni-

* Derived from two Persian words meaning "the Demon."

tude, but once in three days it dwindles away to about fourth magnitude for a few hours. The spectroscope shows that sometimes it is approaching and sometimes receding, so it looks as if it were revolving round something, but round what? Surely here must be another binary system in which, however, one of the pair is dark. That explains, too, the regular variation in light, for at every revolution the dark partner will get in the way and cut off from us some of the other one's light. There are a number of other variable stars too, which appear to be similar to Algol. Spica, in the constellation Virgo, is an example of another type, for it appears to have a dark companion, yet in this case its orbit does not happen to bring it between us and its bright companion, so that the light does not vary.

THE HELIOMETER

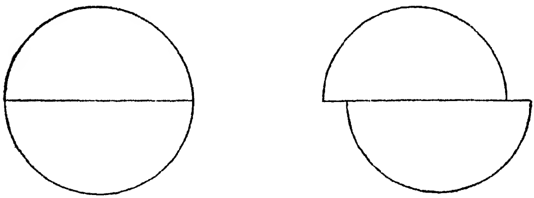
There is one other important instrument which must be mentioned, the heliometer. It is the most accurate appliance known for measuring small angular distances.

It is like a refracting telescope with the object-glass divided across the centre. By the movement of a screw these two halves can be made to slide along, one to each side, and the number of turns of the screw, or parts of a turn, show very exactly how far they have moved.

Now at first sight it seems as if half a lens would only produce half a picture, but that is not so. It pro-

duces a complete picture, the same size as a whole lens would do, but only half as bright. Consequently when the two halves of the lens are together we may think of them as making a picture each, exactly on the top of one another. In other words the result is exactly as if they were one lens.

As soon as the screw is turned, however, the image formed by one lens goes to one side, and that by the



When the two halves of the object-glass are together, as above, the three stars in the handle of the Plough would appear thus :

But when the two halves are moved thus, the three stars would appear as under, and the distance the halves are moved will show the distance between stars 2 and 3 :

FIG. 26. THE PRINCIPLE OF THE HELIOMETER

other the opposite way. Thus, if it is the distance between two stars that is to be measured, the screw is turned until the image of star No. 1, as formed by one-half of the lens, is exactly on the top of star No. 2 formed by the other half. The distance the lenses have moved, then, tells the angular distance between the stars.

HOME-MADE INSTRUMENTS

As I have said already, it is a great mistake to assume that astronomy can only be studied by those who can possess a large telescope.

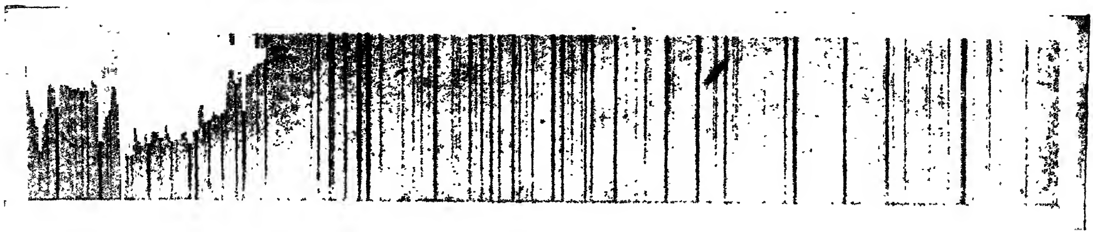
A pair of field-glasses are for some reasons better than a telescope. They have a wider field of view, so that the relative positions of the stars, for example, can be studied with them better than with a large telescope. They will also reveal an astonishing amount of detail in the moon.

How to Use a Camera as a Telescope.

An ordinary photograph camera can be converted quite easily into a telescope. Take out the frame which holds the ground glass, and in its place put a square piece of wood with a small magnifying glass fitted in the centre. To the inside of this fix a little paper tube with a fine thread stretched across it. The thread must be just at that distance from the magnifying glass at which it can be seen clearly.

With this simple contrivance it is easy to watch the transit of a star. Point it at a star low down on the southern horizon, and the tiny dot of light will be seen to creep across the field of view quite quickly.

It is a convenience, when using a camera in this way, to rig up a special support for it so that it can easily be turned in any direction. A little ingenuity will find a way of doing this.



THE SPECTRUM OF THE SUN

This may be called the Sun's "Character," written by itself. A strip of light is split up by the Spectroscope into this broad band, with lines across. Each elementary substance has a set of lines peculiar to itself; there are many such sets here, all mixed up, but by study the different sets can be identified and the composition of the Sun thus discovered.

To face page 128

How to make a Telescope.

A more ambitious telescope can be made on the lines of Fig. 27, with two lenses and cardboard or brown-paper tubes. An object-glass three inches in diameter and forty inches focal length can be bought for about three or four shillings, and a small lens about one inch focal length for the eye-piece for a few pence. These cheap lenses will give a very good view of the moon, or they will do for watching transits, but you must not

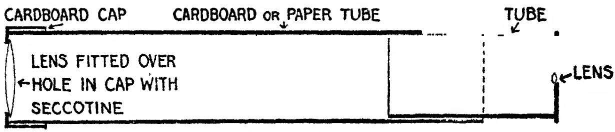


FIG. 27. HOW TO MAKE A TELESCOPE

expect too much for your money. Even a small spectacle glass about 1¼ inches in diameter with a long focus (cost 6d.) can be used as an object-glass.

The large tube must be about as long as the focal length of the object-glass, and the small tube two or three inches.

A really high-class object-glass, two inches in diameter and about twenty-six inches focal length, can be obtained for about a guinea, and with such a lens a very good telescope indeed can be made.

Photographs in an Ordinary Camera.

Some very interesting observations can, as we already know, be made by photographs taken in an ordinary

camera, while an amateur mechanic who can rig up a turntable on which to mount his camera so that it will follow the stars round will be able to get still more interesting and beautiful results.

Equatorial Mounting.

For this purpose the apparatus must rotate at the rate of once in twenty-three hours, fifty-six minutes upon an axis which points to the Pole Star. Very long exposures can be given, and even very faint stars will be found upon the plate. Portions of the Milky Way and such groups of stars as Orion give beautiful pictures in this way.

How to make a Sundial.

In conclusion, some readers may like to know how to make a sundial, one of the oldest of astronomical instruments.

Two pieces of slate, one to form the dial and the other the gnomon, answer the purpose very well, as this material resists the weather and is easy to mark.

The dial may be square or round, as shown in Fig. 28. If it is to be placed in London or anywhere in about the same latitude a copy of this figure may be made to scale, but if the latitude is different it must be altered slightly.

The distances G H and J K must be the same as the latitude of the place as read from the scale at the foot of Fig. 28. The lines G L and K M must be kept the same length, and the points in them where the "hour" lines cross must remain the same. Thus an alteration in the latitude brings about a slight alteration in the

direction of the "hour lines." To make this quite clear I give in Fig. 30 a diagram of a dial as it would have to be drawn for latitude 30 degrees.

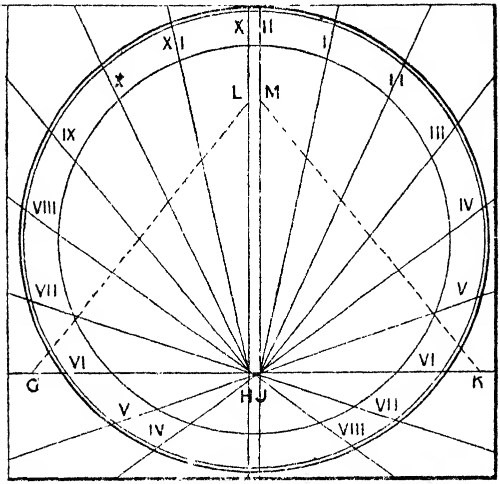
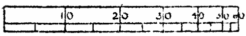


FIG. 28. THE FACE OF A SUNDIAL FOR THE LATITUDE OF LONDON ($51\frac{1}{2}°$)



SCALE FOR LATITUDE

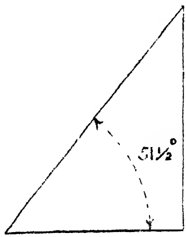


FIG. 29. GNOMON FOR LATITUDE OF LONDON

The gnomon, which must be shaped something like Fig. 29, must be fixed in an upright position between the two parallel lines in the centre of the dial with its

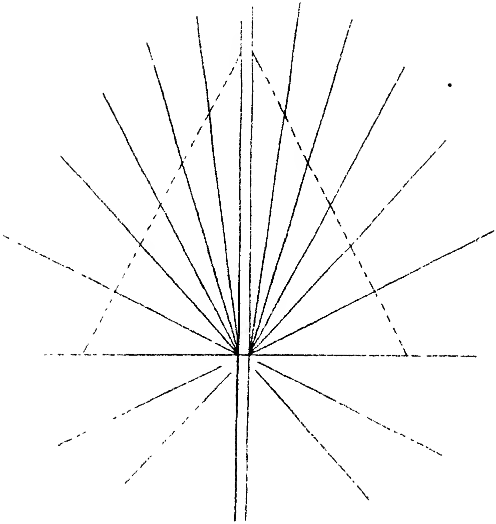


FIG. 30. DIAGRAM SHOWING HOW THE POSITIONS OF THE HOUR LINES VARY WITH THE LATITUDE
This is constructed for Latitude 30°. Compare with Fig. 28.

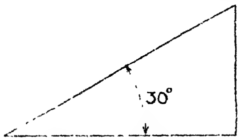


FIG. 31. GNOMON FOR LATITUDE 30°

point at the spot whence the radiating "hour" lines start. Its upper edge must make an angle with the dial equal to the latitude of the place; for London $51\frac{1}{2}$ degrees. It is the shadow thrown by the gnomon which tells the time. The two parallel lines must be drawn a distance apart equal to the thickness of the gnomon.

The dial must be fixed quite level, with the twelve-o'clock mark to the north.

CHAPTER XII

GREENWICH OBSERVATORY

THIS book cannot be concluded without a short description of the most famous observatory in the world.

It is situated in Greenwich Park, on the brow of a hill overlooking the Thames. It was founded by Charles II for the purpose of providing accurate astronomical information for the purpose of navigation, and is a department of the British Admiralty. The original object has always been kept in view, and for that reason, while other astronomers have been making discoveries which have startled the public, the staff at Greenwich have devoted their attention mainly to the much more important work of supplying information as to the precise movements of the heavenly bodies, for the construction of the "Nautical Almanac," without which every ship on the ocean would be "at sea" in more senses than one.

Because of this some of us are apt to think that our national observatory is poor and behind the times, yet nothing could be farther from the truth.

The older part of the buildings was erected by the great Sir Christopher Wren, but the newer parts are quite modern.

The Transit Circle.

The first instrument calls for a word of explanation. I described on page 44 a transit instrument for telling the times when the heavenly bodies transit the meridian. This needs to be used in conjunction with another telescope, also pivoted see-saw fashion, but fitted with a large wheel or circle marked in degrees and parts of a degree, in order to be able to tell not only the time of the transit but how far up the meridian above the horizon the transit took place—such an instrument is called a Mural Circle. These two instruments are now usually combined into one, which is termed a *Transit Circle.*

The Transit Circle at Greenwich is a refractor of 8 inches diameter and about 12 feet long. It is mounted between two massive pillars, as described in an earlier chapter, and the exact angle at which it is pointed is measured on a graduated circle 6 feet in diameter. To ensure the greatest possible accuracy the angle is read off this circle at six different points by six different micrometers, each of which is fitted with a microscope to enable it to be read very exactly. Then the average of the six readings is taken. Thus any error is minimised.

For the same reason there are several vertical lines of spider's web[1] fixed to the eye-piece. The problem

[1] At certain times of the year officials of the Observatory go out into the park in the early morning and collect spiders' webs, so as to have a stock of them.

is to tell the exact moment when the star to be observed passes the centre one, which represents the meridian, but the observer might be over-anxious and record it the fraction of a second too soon, or be too slow and so be a fraction behind. He therefore watches the star cross several which are placed at exactly equal distances apart.

How Electricity helps the Astronomer.

In another room there is a clock so constructed that every two seconds it makes a little "dig" in a moving strip of paper. The observer holds in his hand a little electric push which he presses just at the moment when he sees the star cross a line (or "wire," to use the technical term), and when he does that the clock, to which the switch is connected electrically, makes an extra "dig" in the paper. When he has finished he goes to this clock, examines the paper, and by measuring the distance of the odd "digs" from the regular two-second "digs" he is able to see very exactly the times of the transits of the star across the wires. Then he takes the average as before.

An Equatorial Telescope.

Not far from the transit circle is a circular room with a dome-shaped roof containing one of the large Equatorial Telescopes. It is a refractor, and is called equatorial because of the way it is mounted. It can be turned in any direction, and then, having been fixed upon a certain star, clockwork can be started which

slowly moves it round to follow that star. It is 28 inches in diameter. The dome has a slit in it which can be uncovered when required, and the whole roof turns round so as to bring the slit opposite the part of the sky under observation.

Thus, we see, a telescope fixed in the manner of the transit circle is really a measuring instrument for taking exact measurements of the position and movements of the stars and planets, while those mounted as "equatorials" are for examining fine details and peering as far as possible into the depths of space. Briefly the one is for measuring and the other for examining.

The Altazimuth.

In a little building by itself is a telescope called an Altazimuth. Like the transit circle it is a measuring instrument, but it can be turned to any part of the sky and has large graduated circles by which its exact direction can be ascertained. It was put up specially for studying the movements of the moon. The curious name arises from the fact that it is intended to define the position of a body by means of its "altitude" or angular distance above the horizon and its "azimuth" or angular distance east or west of the meridian.

More Equatorials.

Another large building with a dome-shaped roof contains two more equatorial telescopes, one a refractor 26 inches in diameter and the other a reflector 30 inches in diameter.

There are instruments for measuring rainfall, sunshine, wind, and so on, also a room where the chronometers for the Navy are tested and a department devoted to observations of the vagaries of the magnetic compass needle, but these hardly come within the scope of this book.

CHAPTER XIII

THE "FIXED" STARS

IT is estimated that there are about one hundred million stars in the sky. At one time it was thought that their number was infinite, and that beyond those which we could see there were others extending onwards for ever, but it is now believed that if that were so, the whole sky would be bright by night, as well as by day, and not simply studded with bright specks, as we see it to be. They are divided up into groups or constellations, each of which has a name, and they are also classified according to their brightness. The brightest are said to be of the first magnitude, then come the second magnitude, third magnitude, and so on. Those of the sixth magnitude are about the faintest that can be seen with the naked eye.

How the Stars are named.

Many of the brighter stars have proper names of their own, such as our old friends Vega and Capella, but it is the custom to describe all stars by the constellation to which they belong, and a distinguishing letter or number in the order of their brightness. For instance, Vega is called Alpha Lyrae, which means the brightest star of the constellation Lyra, and the next brightest

of that group is Beta Lyrae,* Alpha and Beta being the first and second letters of the Greek alphabet. When all the Greek letters have been allotted the Roman letters are used and then numbers.

Right Ascension and Declination.

The position of a star in the heavens is usually stated in "right ascension" and "declination."

This is not unlike our method of designating the houses in which we live. My house is No. 44 in a certain road, and if a friend desires to pay me a call he first finds the road, and having found it, the number 44 tells him the position in the road of the house which he wants.

Now the meridian, as we know, is an imaginary line drawn across the sky from north to south, exactly overhead, and as the earth swings round upon its axis, this line must necessarily sweep across the face of the sky; moreover, the earth turns with such perfect regularity that at the same time (sidereal time, of course) every day, the meridian is always in the same position on the face of the heavens; so, if we say that a certain star, Capella for example, is on the meridian at 5 hours 10 minutes 23 seconds, we know that it lies somewhere along the great north-and-south line, which is ruled across the sky by the meridian every day at that time. The exact moment, then, by sidereal time, when a body is on the meridian (which is called the "right ascension" of that body) defines the position of a line across the

* Lyrae is the Latin "possessive case" of Lyra. It means "of Lyra."

heavens along which the star is to be found; as it were, the street in which the star lives.

Declination is the angular distance from the celestial equator to the star measured along this line. It may be north of the equator (which is sometimes shown by the sign +) or south (which is indicated by −), and it will be seen to show the place of the star on the line much as the number shows the position of a house in a street.

The celestial equator is an imaginary line drawn round the heavens exactly above our earthly equator, and, of course, at right angles to the meridian.

In a previous chapter we noticed some of the wonderful things which the spectroscope has told us about the stars.

Some Stars can be seen to be moving.

The spectroscope, however, only tells us of motion either towards us or away from us, but there are some which we can actually see are moving to one side by direct observation. There is one, for instance, known as "the Runaway Star" (because it is travelling so fast), which has a speed across the sky of 227 miles per second (not a bad speed for a "fixed" star!), yet it is so far off that it takes 257 years to cover a distance across the heavens equal to the diameter of the moon.

Our own Sun is moving.

Our sun itself is travelling in the direction of Vega, carrying its retinue of planets with it at a rate of some-

where between twelve and eighteen miles per second. This we know from the fact that the stars near Vega seem to be opening out, just as objects always appear to do as we approach them; while those in the opposite part of the heavens appear to be closing together.

Speeds of some "Fixed" Stars.

To mention the speeds of a few of the well-known stars: Sirius is approaching at about ten miles per second, and Vega at about the same rate; Arcturus is approaching at about five miles, while Capella is receding at about fifteen miles per second. These motions, I may repeat, are called "proper motions," to distinguish them from the "apparent motions" described in chapter i.

Distances of the "Fixed" Stars.

The distances of some of the nearest stars have been ascertained by the method described in an earlier chapter. The nearest is one in the southern hemisphere called Alpha Centauri, which is twenty-five millions of millions of miles away. This figure is altogether too great for our minds to realise, but this little trick will help us. Lay a halfpenny on the table, and imagine its edge to represent the orbit of the earth 186,000,000 miles in diameter. On that scale Alpha Centauri would be just over two miles away.

Another way to reduce the figure down to something which we can understand is to express it in the number of years which light takes to reach us from the star, in

this case about 4½. The light from Vega takes about 30 years, Capella 32, Arcturus 100, and Sirius 8½ years to reach us. That from some of the farthest stars probably takes thousands of years, so that one of them might have been extinguished in the time of Christ without our being yet aware of the fact, since light which had started on its journey so long ago as that would still be on its way here.

A Celestial Guide-book.

Strangers who visit London in the holiday months can often be seen finding their way about by means of a guide-book, and it is necessary to provide something in the nature of a guide-book for those who are strangers to the northern heavens.

I have told already how to find the Plough, Cassiopeia, Vega, and Capella, the four points of the heavenly compass. When you have found these turn to the table (page 143) and there you will find the principal constellations which can be seen in England, and it will not be difficult to trace from one to another until you have found them all. In most cases some stars in one are made to point to the next on the same principle that we found the Pole Star by the Pointers.

The "Fixed" Stars

TABLE OF THE PRINCIPAL NORTHERN CONSTELLATIONS

Degrees.		
35	Ursa Major (The Great Bear)	See chapter i.
10	Ursa Minor (The Little Bear)	These stars form the outline of a saucepan, like the Plough, only deeper. The Pole Star is at the end of the handle.
30	Cassiopeia . . .	See chapter i.
60	Bootes (The Herdsman) .	Imagine the handle of the Plough bent downwards a little and it will point to a first-magnitude star, Arcturus, the chief in Boötes. Arcturus and two others form a nearly equilateral triangle.
50	Lyra (The Lyre) . .	See chapter i. The chief star is Vega.
45	Auriga (The Charioteer) .	See chapter i. The chief star is Capella.
45	Perseus	A festoon of stars stretching from near Capella towards Cassiopeia. There are two bright stars below the middle of this, the upper of which is Algol.
50	Cygnus (The Swan) . .	This is near Vega, and can be identified by a number of stars forming an outline like a boy's kite.
90	Aquila (The Eagle) . .	Look for three stars in a row, pointing towards Vega. The middle one is the first-magnitude star Altair.
105	Capricornus (The Goat) .	In line with the three stars of Aquila in the opposite direction from Vega.
70	Pegasus (The Flying Horse)	Imagine the line from the Pointers continued beyond the Pole Star until it reaches four stars forming a square. All except the left-hand top one belong to Pegasus.
50	Andromeda . . .	The top left-hand star of the above "square" belongs to Andromeda.
70	Aries (The Ram) . .	Look for three stars in a "crooked line" some distance to the left of the "square."

Degrees.		
75	Pisces (The Fishes) . .	This lies between Aries and Pegasus. (No conspicuous stars.)
75	Taurus (The Bull) . .	To the left of Aries and below Perseus and Auriga. There is one first-magnitude star, Aldebaran; it lies amid a beautiful cluster of small stars called the Hyades, while to the right and a little higher up are another cluster called the Pleiades.
70	Gemini (The Twins) .	The next constellation to the left of Taurus. Two bright stars, the upper one Castor, the lower one Pollux.
75	Leo (The Lion) . .	If the line through the Pointers be continued, *away from* the Pole Star, for a little more than the same distance, it will bring you to Leo.
70	Cancer (The Crab) . .	Between Leo and Gemini.
110	Scorpio (The Scorpion) .	Imagine a line from the Pole Star, passing midway between Vega and Arcturus; it will lead direct to Scorpio. There is one first-magnitude star, Antares.
105	Libra (The Scales) . .	Between Scorpio and Virgo.
105	Sagittarius (The Archer) .	Between Scorpio and Capricornus.
105	Aquarius (The Water-carrier) . . .	Between Capricornus and Pisces.
85	Canis Minor (The Little Dog)	Immediately below Gemini. One first-magnitude star, Procyon.
90	Orion	The most beautiful constellation in the whole sky. Just beneath Taurus and Gemini. It can be found, too, by a line from the Pole Star through Capella.
105	Canis Major (The Great Dog)	This lies below and to the left of Orion. It contains Sirius, the brightest of all the fixed stars, often called the Dog Star.
100	Virgo (The Virgin) . .	Below and to the right of Arcturus will be found the first-magnitude star Spica, the one bright star in this constellation.

The number in the first column denotes the distance *in degrees* from the Pole Star to about the centre of the constellation. The distances can be judged fairly accurately by the eye from the fact that Capella is 45° from the Pole Star.

CHAPTER XIV

ARE THE STARS INHABITED?

PEOPLE who ask this question usually mean the word "star" to cover all the heavenly bodies except the sun and moon.

It is of course quite impossible for us to give any answer from direct evidence. We can never hope, that is, to have telescopes powerful enough to see people, even on the moon, or the nearest planets. All that can be done is to find out, as far as we can, the conditions which exist upon the various bodies, and then see if they are such as to make it reasonably probable that people anything like ourselves can be living there.

Mercury.

Many of the planets we can rule out of the question almost at once. Mercury seems to have very little atmosphere, for when it passes across the face of the sun, in what is called a "transit of Mercury," it appears simply a dull black dot, whereas if it had air like we have there would be a bright edge to it. There are other reasons, too, for believing it to be a dry lifeless globe resembling the moon.

Venus.

Venus, on the other hand, has an abundant atmosphere with watery clouds, and in many ways it resembles the earth; indeed, when we look at it we get a very good idea of how our planet would appear if seen from Venus or Mars. This very fact that it has an atmosphere, with clouds in it, prevents us from seeing anything of the planet itself, however, and so we are unable to glean any information about its state by that means. It also prevents us from finding out for certain how fast it rotates, and if, as is thought to be the case, it always keeps one side turned towards the sun, as the moon does towards the earth, it must certainly be a place which we earth-men would not care to have for a residence, for there must be eternal day in one hemisphere and eternal night in the other, and it is difficult to say which would be the more unpleasant.

Jupiter and Beyond.

Jupiter, Saturn, Uranus, and Neptune are not, as far as we can tell, in a sufficiently solid state to permit of their supporting life, and the only remaining planet is Mars.

Mars.

Leaving out the moon and the little planet Eros, Mars is our nearest neighbour, and when he is in opposition, that is to say, when he and the earth are both on the same side of the sun, the two are very near together. Some "oppositions" are more favourable

than others, for since both bodies describe ellipses round the sun, their distance from it varies, and if an opposition happens to occur just when the earth is farthest away from the sun and Mars is at its nearest to the sun it is easy to see that the two will then be specially close. At such times many telescopes are directed to Mars, and since he appears to have a very thin atmosphere with few, if any, clouds, a great deal of detail can be seen upon his surface, and the true meaning of these details has been the subject of much discussion.

Mars' Thin Atmosphere.

It is believed that his atmosphere is thinner than that on the top of the highest earthly mountains, and from what mountaineers tell us, we know that it would be difficult for people constituted as we are to live under those conditions. Still, if we were made a little differently, with larger lungs for example, we might be able to exist even in that thin air, and so it does not follow from that that people could not live on Mars. In the same way, the fact that there seems to be at the best only a very little water on the planet does not make it absolutely uninhabitable.

The Famous "Canals."

In 1887 an Italian astronomer named Schiaparelli noticed certain strange lines on the surface of Mars, to which he gave the name Canali, meaning channels. That word is so suggestive of our word canals that people

have got to think of these as artificial waterways such as we know by that name, and many extravagant things have been written about the supposed wonderful inhabitants of Mars who are assumed to be engineers of such marvellous skill as to be able to dig canals thousands of miles long and broad enough for us to see them from the earth. No serious astronomers go as far as that, however; but Professor Lowell, who has studied the question very closely, is inclined to think that Mars having so little water, the inhabitants, if there are any, would have to make the best possible use of what there is, and so he thinks they may indeed construct waterways; what we see, he suggests, are not the channels themselves but tracks of cultivated country lying along them and owing their fertility to the water which they contain.

On the contrary, other astronomers ascribe the strange lines to cracks or fissures in the planet's surface, or mountain ridges, and it has even been suggested that they may not really be lines at all but small marks lying in rows which look like lines. For it must be understood that they are very faint even in the best telescopes, and there are some among the foremost astronomers who cannot see them at all.

Mars must be very Cold.

There can be no doubt that Mars' atmosphere being so thin and containing so little watery vapour it must be intensely cold there, and so another suggestion is

that it is covered with a layer of ice, and that cracks or channels in the ice form the lines.

A prominent feature about Mars when seen through a telescope is a brilliant white patch at each of the poles which resemble what the masses of snow and ice at the poles of the earth would look like if we could get a distant view of them. During the planet's summer these seem to melt; on one occasion one of them entirely disappeared, and the idea has been suggested that the "canals" are intended to carry this snow-water to the other parts of the planet for irrigation purposes. It is pretty certain, however, that it would not flow that way of its own accord but would have to be pumped.

Thus we see, since eminent astronomers disagree, no one can say definitely whether Mars is habitable or not. Professor Lowell thinks it is, another great American astronomer considers that only a very low form of life can exist there, while an equally great English authority asserts it to be "absolutely uninhabitable."

The Distant Stars.

Of the distant stars we can be quite certain that the bright flaming suns are without inhabitants, but the "dark" stars are different; it is quite possible that some of them are in a condition similar to that of the earth, and so may have living people upon them. Moreover, it would be strange if our sun were the only one to have a retinue of satellites, and since the planets must be invisible from the stars we may fairly assume that there may be planets, which we cannot see, re-

volving round those distant suns, and some among them would be almost certain to be like our earth. Therefore, it seems very probable that there are people in other parts of the universe; still we can only say probable, no more.

CHAPTER XV

HOW TO TELL THE DIRECTION BY THE SUN AND MOON

IT is often convenient to be able to tell the direction by the heavenly bodies. At night the Pole Star shows the north, and if it should be hidden by clouds anyone familiar with the constellations will be able to get a good idea of where it is, which for practical purposes is as good. For example, if we can see the Pointers, they will answer the purpose almost as well.

By the Sun.

In the daytime the sun will serve just the same purpose as the Pole Star, only it is not quite so simple. The sun always rises near the east and sets not far from the west, while at noon it shows the south. Between these times we can easily find the south with a watch.

Hold the watch in your hand, face towards you, at such a slant that the sun shines upon its edge. Then turn it round so that the hour-hand points to the sun, and imagine an extra hand lying exactly midway between the hour-hand and twelve o'clock. That imaginary hand will point to the south. This only

answers between the hours of six and six, but at other times the sun is near enough due east or west to make the use of a watch unnecessary.

By the Full Moon.

By a somewhat similar method we can tell the direction by the moon, only in that case we must make an allowance for the "age" of the moon. We know that when it is full it is exactly opposite the sun. The procedure, then, to find the south is exactly the same for the full moon as it is for the sun.

When the Moon is not Full.

We know, too, that when it is waxing from new to full, its movements are in advance of the full moon, and when waning they are behind. For every day before full the moon will be about fifty minutes earlier and for every day after about fifty minutes later. We must therefore "correct" our working accordingly.

If the watch is a "keyless" one this is very easy. If the moon is waxing, you have simply to put your watch *on* fifty minutes for every day till full. If it is waning, you must put it back fifty minutes for every day since full. You can then proceed exactly as in the case of the sun.

How to tell the Moon's Age.

If you take an interest in these things you will probably remember the date of the last full moon,

or you may be able to find it from a pocket calendar. If both these means fail, you can estimate the age of the moon by its shape. When the full round side is to the right the moon is waxing, when to the left it is waning. When you see it as if it were cut exactly in half it is midway between new and full, say about seven days before or after full, as the case may be. So, also, when it is gibbous, it is somewhere between half and full, or crescent, between half and new. With a little practice you will be able to judge the moon's age approximately, by simply looking at it.

Of course, the moon rises near the east and sets near the west, just as the sun does, whatever its age may be, so that when it is low down near the horizon you can get the direction from it easily without the aid of your watch.

INDEX

Index

Index

PRINTED BY
WILLIAM BRENDON AND SON LTD.
PLYMOUTH